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DEVELOPMENT OF PROCESS SYSTEM FOR TREATMENT OF OIL CONTAMINATED SOILS & SLUDGES IN THE NIGER DELTA

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DEVELOPMENT OF PROCESS SYSTEM FOR THE TREATMENT OF OIL CONTAMINATED SOILS AND SLUDGES IN THE NIGER DELTA

Thesis submitted in partial fulfillment of the requirements for the award of Ph.D in Process System Engineering of Cranfield University.

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1.0 ABSTRACT

One of the major problems with process equipment/systems set up in Nigeria is the lack of sustained productivity, arising from the basic inappropriateness of such equipment/system to the technological level of the country. The pollutions arising from the Oil & Gas exploitation activities in the Niger Delta were highlighted.

In this project, the development of a unique processing system capable of advantageously treating oil contaminated soils and sludges in the Niger Delta was undertaken. The specific constraints in that terrain are outlined. The treatment systems that are currently available worldwide which are applicable to the Niger Delta have various limitations. The system designed had to be able to overcome all those limitations. Design superiority and success in the market place being two desirable aspects of a product, the project focused on the possibility of processing the contaminated materials at a higher rate without compromising quality. The need to generate its own fuel for firing burners and diesel for firing the electricity generators was one of the main drivers for the project. The system developed was tested at pilot level for effectiveness in those key areas.

A totally energy-independent process has thus been created, which generates energy for the material being treated. This will guaranty the success in the market place in treating the contaminated sites of the Niger Delta, at commercial rates that are about a third of the current rates in the region. It is also estimated that capital and operating costs will be less than half of foreign built units, which ensure faster attainment of breakeven point.

The future work that could be undertaken in this area include the field trials of a mini-sized processing unit and the eventual translation of processing parameters and information into a life size, commercial system able treat materials as required.

2.0 INTRODUCTION

2.1 PROJECT DESCRIPTION

The project is aimed at developing an appropriate system for treatment of oil contaminated soils and tank bottom sludges in the Niger Delta region of Nigeria. The following characteristics are expected to apply to the system development:

a. Appropriateness of Technology with respect to the region or the country Nigeria.
b. Mobile
c. Energy Independent; as it has to generate all its energy requirement, irrespective of the constraints of mobility, while meeting treatment targets.
d. Enhanced treatment capacity, irrespective of the constraints of mobility, while meeting treatment targets.
e. Reduced treatment cost without compromising profitability and quality.
f. Improved availability on account of reliability and maintainability without recourse to foreign expertise.

2.2 JUSTIFICATION FOR THE PROJECT

Nigeria is the sixth oil producing country in the world. Activities in this industry have been going on in Nigeria since 1956 when crude oil was first drilled in the country. The coastal swampy region of the Delta of the River Niger is the base for most of the operations in the Oil & Gas Industry. Since the inception of these activities, numerous oil spills have occurred with consequent damage to the ecology of the region. The reasons for these spills include the following:

a. Plain sabotage of Oil pipelines and facilities.
b. Rupture of pipelines arising from old age.
c. Rupture of pipelines arising from armed conflicts.

These spills are scattered all over the Niger Delta, because pipelines crisscross the entire region. A map of Niger Delta is shown in fig.1, while fig.2 shows the map of some of the pipelines in the region.

Due to the very low level of infrastructural development, the spill sites are not easily accessible.

Treatment systems exist in the world which are applied to normal oil contaminated soils. These range from bioremediation methods to heating methods, which volatilize the oil contained in the soil. [CORBITT, R.A; EPA (US) CIRIA]
It is the normal practice to have a major treatment unit positioned in an operational base and the oil contaminated soils transport to it.
In such cases, and in the developed world, the cost of transportation may not be excessive; and the exercise of transportation may not upset communities that lie in between. Where mobile systems are taken to the contaminated sites, the costs may not be excessive because utilities, energy and infrastructure are available. The limitation on treatment rate that mobility imposes will therefore not matter much.
Additionally, treatment systems brought in from the developed world into Nigeria are given to frequent down times on account of lack of maintainability and general inappropriateness to the environment.

The peculiar conditions that exist in Nigeria are as follows:-

a. Inadequate access to the contaminated sites.
b. Hostile communities on the way to the contaminated sites which make it expensive and unsafe to transport such soils.
c. Unavailability of utilities, especially energy source in those remote and stranded locations.
d. Need for improved rate of treatment not limited to physical size of the mobile system.
e. Relatively low level of Technological sophistication of the people.

It is hoped that at the end of the project, a system will be developed and made available which will have the following:-

- Be totally energy independent and mobile.
- Have the economic advantage of reduced processing cost combined with increased rate of treatment relative to sizing for mobility.
- Be appropriate to the technological level of Nigerians and therefore have improved availability and maintainability.

Figures 3a & 3b show some oil spill sites with the lagoon of oil.

Finally, the successful development of this process and the lessons learned therein will aid in the development of numerous other processes in Nigeria, which will be of appropriate technology.

2.3 PROBLEM DEFINTION

2.3.1 TECHNO – ECONOMICAL

The Niger Delta in Nigeria, a coastal plain composed of sandy deposits, is one of the areas on this planet that receives the heaviest rainfall in the year. It is also the base for prospecting, production and processing of crude oil and natural gas for many multinational operators in Nigeria. Since the 1950s and 60s, companies such as Shell, Mobil, Elf, Agip and Texaco have been active in the region. Crude oil is produced in Nigeria from this delta at the rate of nearly 3 million barrels every day. (DPR NIGERIA: SHELL NIGERIA).

The Niger Delta region is an area of not less than 70,000 km² hosting more than 8 distinct tribes. (SHELL NIGERIA). Over these years of oil prospecting activities, the area has largely been neglected, with the consequence of severe lack of basic infrastructure. Access roads are inadequate, electric power and even potable water are absent in many parts of the Niger Delta. The prevalent occupations of the people in this Niger Delta are farming and fishing in the creeks and rivers of the area.

Oil prospecting, production and processing activities invariably lead to some pollution of the areas in which they are taking place. The situation is no different in the Niger Delta. If there is a difference, it is in the degree of severity. The lack of infrastructure affects possible plans for clean up operations.
The pollutions that occur in the Niger Delta area from oil drilling activities include:-

a. Oil spills on land and water.
b. Dumping of Drill cuttings and such wastes (on land and water).
c. Dumping of oil sludges from tank bottoms.
d. Petroleum product spills due to ruptured/sabotaged pipelines.

Due to the geological nature of the Niger Delta, the pollution sources listed above have the tendency to spread and to migrate downwards even into ground water and of course laterally into the creeks and rivers. The consequences include, but are not limited to:-

a. Inability of the area to support life (plant and animal), with consequences on the lives of the residents.
b. Existence of hazardous environment, which could easily be combustible, especially considering the ignorance of the indigenes. Some accidents have occurred due to this situation.
c. Contamination of ground water and surface water leading to lack of potable water.

There have been no less than 100 spills of various severities in the region.

Since the commencement of oil-related activities in the Niger Delta, no serious attempts have been made to treat the regions impacted by those pollutants. For instance, soils contaminated by a crude oil spill over 35 years ago, during the Nigerian civil war, are yet to be treated. The typical reaction from the oil producing companies and government is a combination of mopping up the spill and paying compensation to a few powerful individuals in the area affected. The soil left after the oil clean up exercises is so heavily laden with crude oil that it is unable to support any form of agriculture. Such soils abound in the Niger Delta area – especially in remote areas where pipeline spills frequently occur. A comprehensive network of pipelines (crude oil and gas) exist in the Niger Delta. Most of the areas where these pipelines pass through are not usually accessible. A partial list of pipelines spills and fires is shown in Table 1.

Tank farms are used by the oil producing companies in their terminals for the storage and settling (stabilization) of the produced oil. All these terminal are on-shore in the Niger Delta. A list of the operators, production capacities and export terminal is shown in Table 2.

Typically, over time, a thick sludge made up of water, oil and sand (silt) accumulates at the bottom of the tanks. The quality of the sludge is fairly constant. This sludge takes up economic tank space and also holds back a reasonable amount of crude oil. It was found to contain an average of 45% oil when freshly discharged. The average properties of the sludge and the contaminated soils is shown in Table 3. By regulation, each tank must be de-sludged once every five years [DPR NIGERIA].

Recently, (in 2001) the Shell Petroleum Development Company of Nigeria through a contractor, imported and installed Thermal Desorption Unit (from the U. S.A) for treating the sludge in one of their terminals (on Bonny Island). This unit was severely handicapped in location and operation. The

unit was only able to treat/process wastes which were transported to its location. The transportation of soil or sludge to it involves multiple logistics problems, which include, excavation, trucking, barging, etc to the location and back to original source of waste generation. The system has been abandoned since Feb 2004[FIDELITY BANK]. Some of the problems it encountered were high breakdown frequency, inappropriateness to the Environment, excessive cost of operation, etc.

The soils were transported through about 200 km over water and land to Bonny and back to its original location.

A treatment process which will be able to recover most of the oil and have the flexibility to move from one location to the other is necessary.

Presently, some of the oil terminal operators dump the sludges in pits lined with impervious materials, awaiting an appropriate treatment option/facility.

TABLE 1: LIST OF PIPELINE SPILLS, FIRES AND OTHER RELATED INFORMATION

SOURCE	INFORMATION
Sunday Concord 27/9/98	Elder Statesman Harold Dappa-Biriye states, "heavy damage has been caused by oil spills".
Tuesday Vanguard 26/1/99	Vandalisation of NNPC pipelines in forest bordering Enugu, Anambra and Kogi States. Residents fetching petrol and kerosene from the scene. Several million litres spilled after delivery line was vandalized.
Friday Guardian 22/10/99	Ekakpamre Youths Council give Shell 14-day ultimatum over spill. Damaged pipeline caused explosion. 500 hectares of land destroyed by fire. Federal Government blames the heinous environmental crimes of multi-national Oil Companies for Niger Delta crisis. Gave firms six weeks to clean up communities. Accused companies of breaching good environmental management procedures. Quote by Minister of State for Environment, Dr. Ime Okopido, "Over the past decades, the Niger Delta has been overrun through deliberate over-exploitation carried out in total disregard of the basic principles of sustainable environmental management.

	Close to 4,000 oil wells have been drilled since 1937. These sites constitute potentially polluted sites at which drilling wastes, drill cuttings, oily sludges and various toxic hazardous chemicals have been disposed.
Thursday Guardian 22/6/00	Unconfirmed number of people feared dead in a raging fuel pipeline fire, which devastated farmlands in Okpe, Delta State.
Thursday 29/6/00	Six children drown in abandoned oil well owned by SPDC, in Uruan, Akwa Ibom State. Host communities seek compensation of more than 10 billion Naira for alleged gross negligence leading to the deaths of the children and intermittent spillage of crude from the well.
Friday Guardian 14/7/00	Government declares site of pipeline oil fire in Okpe, Delta State disaster area. Further entry to the scene was forbidden, as the air was still thick with hydrocarbon fumes. Minister of State for Environment said, "These sites would require huge resources to mitigate the environment and restore the natural biodiversity, fauna and flora".
Thursday Guardian 20/7/00	Gov. Alamieyiesegha said a probe of recent pipeline inferno in Ororokpe, 16 km from Warri, Delta State, was necessary.
Monday Guardian 24/7/00	Suspects caught vandalizing PPMC pipelines and siphoning oil in Osisioma, Omoku, Komkom and other villages in Abia and Rivers States. Recent oil pipeline fire in Okpe, Delta State.
Tuesday Guardian 25/7/00	Fire outbreak in Delta State, 28 km from Sapele, killing unconfirmed number of people and destroying several acres of farmland. Lagos State Govt warned of possible outbreak from broken NNPC Oil pipelines. Leakage already causing serious environmental degradation. NNPC's inefficiency and failure to constantly monitor the pipelines blamed for rupture, as lines due for replacement 8 years previously were yet to be replaced.
Wednesday Guardian 26/7/00	More pipeline vandalisation gives rise to fires in Egborode, Delta State. Senator Stella Omu stated her belief that Oil Companies operating in the Niger Delta had not met

	the International standard on maintenance of oil pipelines, as statistics show more cases of equipment failure in Nigeria\'s Oil and Gas sector than in other Oil producing countriews in the world.
Tuesday Guardian 1/8/00	Vandalised pipeline leads to fire in Ororokpe, 16 km from Warri, Delta State.
Thursday Guardian 3/8/00	Six arrested by Lagos Police for vandalisation of NNPC pipelines at Imote, Ojo local govt council. Pipeline vandalisation common feature around communities surrounding the Satelite and Navy towns on Badagry expressway.
Tuesday Guardian 8/8/00	Five Ijaw youths arrested for attempted vandalisation in Bayelsa State. Two Ijaw youths caught vandalizing NAOC pipelines. Delta communities threaten to shut down Shell's facilities over spill in Ughelli North (Well 13), the worst ever, in Delta State. Spill caused a huge overflow into streams running through 8 communities. Water bodies 10 km radius of the spill were impacted. Spill was so massive that its thickness on water around the immediate vicinity of the spill measured 12". The well shot out crude oil almost 100 m into the air, and then spread to surrounding vegetation by wind action. Pressure from the well was so fierce that the noise of gushing crude could be heard half a kilometer away from the spill point. Minister of State for Environment, Ime Okopido, who visited the site, told journalist that about 1,000 barrels of crude oil were being spilled daily. Impacted communities said, "all farmlands have been destroyed", and that fishponds and other aquatic life had been devastated and water wells polluted.
Friday Guardian 11/8/00	Communities blame spill on Shell's safety standards, and advised Shell to shut down its flow stations and installations in the area until their compliance with International drilling and safety standards. Spill occurred when the wellhead at Well 13 was removed, causing several barrels of crude to spill into the creek and environs.
Wednesday Guardian	Five arrested in connection with theft of wellhead

16/8/00	leading to heavy spillage, which affected over 10 communities. Seven more vandalisation spots discovered around Adje Elume axis, Delta State.
Friday Guardian 18/8/00	Village head of Ekorinim, Cross Rivers State, appeals to Federal Govt to assist in assuaging the effect of previous week's pipeline rupture and inferno. Resulting spill destroyed crops, farmlands and aquatic life in the Calabar River. Rupture was due to pressure.
Monday Guardian 21/8/00	Tendency for profit maximization by oil companies has been identified as a major cause of non-implementation of job hazards analysis in EIA analyses. The obvious result of the non-implementation has been environmental pollution.
Wednesday Guardian 23/8/00	Group Managing Director of Northern Nigeria Development Company laments continued neglect of the Niger Delta, a region still lacking basic infrastructure, social amenities, and even potable water.
Friday Guardian 25/8/00	Pipeline vandalisation resulting in spill. Petroleum products still flow from broken pipeline in Abia State.
Tuesday Guardian 12/9/00	Frequent and incessant rupture of pipes due to ageing equipment.
Tuesday Guardian 19/9/00	Vandalisation of Shell's pipeline in Delta State resulting in massive spill.
Wednesday Guardian 1/11/00	Lives of victims of Jesse pipeline tragedy of 1998, still hand in the balance. Vandalised pipeline (in Jesse, Delta State) led to huge inferno, with over a thousand dead.
Thursday Guardian 7/12/00	50 arrested for vandalisation at rupture pipeline site in Lagos.
Tuesday Guardian 19/12/00	Vandals arrested in Delta and Rivers States. NNPC to replace old and rusty pipeline, which rupture incessantly.
Thursday Guardian 21/12/00	Government accused of not doing enough to check environmentally degrading activities of oil companies in the Niger Delta.
Monday Vanguard 26/2/01	American Senator, Russell Feingold, expresses surprise at the level of devastation, deprivation, and pronounced absence of wildlife in the Niger Delta.
Friday Guardian 2/5/01	Major oil spill denied by ExxonMobil.

Thursday Guardian 10/5/01	Chevron records massive spills in Delta State.
www.Shellnigeria.com 16/5/01	Major oil spill at SPDC's Yorla well – 10 in the Ogoni area just over one kilometer from the nearest community. A mixture of oil and gas was spraying from the well – head.
Shell Wide Wed Thursday 13/6/01	Oil spill gives rise to fire in Gio Kporghor (Tai LGA-Ogoni). Oil spill at Angiamagbene, which affected Nun River and Diebu Creek flow stations.

TABLE 2: TERMINALS OF MAJOR OIL PRODUCERS IN THE NIGER DELTA

COMPANY	**TERMINAL**	**PRODUCTION VOLUME (APPROX) MMbbl/d**
Shell Petroleum Development Company	Bonny and Forcados	1.2
ExxonMobil	Eket	0.7
ChevronTexaco	Escravos	0.6
TotalElf	Obagi	0.5
Agip	Brass	0.4

2.3.2 SOCIO-POLITICAL

Nigeria which had independence from Great Britain in 1960, experienced a post independence period of military leadership covering about 30 years. In the year 1999 the leadership changed to a democratically elected group. Prior to that change, the country had been suspended from the Assembly of Commonwealth of Independent States and economic sanctions were hanging over the nation. Thus, it became a very risky place for foreign investment, and the possibility of importing treatment plants (for the sludges) into Nigeria was impaired. The economic environment only started improving in 1999, with the advent of a democratically elected government. Full confidence will take some time to develop, as the international community is uncertain of the ability of the Nigerian military to refrain from dabbling into politics. Fig. 4 shows the map of Nigeria and the neighbors.

The technological level of the nation, Nigeria, is far below the situation in developed countries. Subsequently, systems that will be operated in Nigeria will have to be not too far from rudimentary level. There is therefore the need for appropriateness of technology for these systems, which will be operated by Nigerians in Nigeria. In the case of a treatment process for sludge and oil contaminated soils, the process will necessarily meet the stipulation of the Environmental regulating bodies- Ministry of Environment and the Department of Petroleum Resources of the Ministry of Petroleum. Since work on this process is being developed here in Cranfield and in Port Harcourt, Nigeria, it will also need to meet the environmental emission regulations of the international communities such as British Standards and the United States E.P.A. Additionally, the treated soils need to still be viable for agricultural use by the locals.

Finally, due to the lack of infrastructure in the Niger Delta area, the system being developed will be able to move from one place of pollution to the other and treat sludge and soil without extensive modification. It should also be self sufficient in terms of facilities and energy.

Fig 4: Map of Nigeria showing neighboring countries

2.4 DESIGN TARGETS

The process being developed will need to fulfill the underlisted minimum standards. It should be:

- **SIMPLE**: The users/operators in Nigeria have to be able to understand the purpose and principles of the system and should be able to operate the system with very few manipulation, which will not result in any damage to the equipment, personnel and environment.

- **RELIABLE:** Reliability has been defined as 'the probability that a component or system perform its functions over a projected time period if used in a proper way, given that the components or system was to be considered new at time zero [CROWL, D.A et al; KOULEN,J.L.A]. In the development of a treatment system for contaminated soils, the 'projected time period' will be the time set aside for a treatment campaign, or time between scheduled turn-around or major maintenance programmes (during long-running campaigns of treatment).

- **ROBUST:** This is the 'property of a component or system to remain healthy and operable if not utilized in a proper way for a certain time [CROWL, D.A. et al, KOULEN, J.L.A]. In general, it is the ability of the system to stand mis-operation as well as equipment failure.

- **ENERGY SUFFICIENT:** The system being developed will have to work in remote areas with poor access roads and facilities. It needs to be able to generate its own fuel and other utilities for sustained operations.

- **COST EFFECTIVE:** The system should be able to recover oil from the contaminated soils and sludge at such a level that it will be economically sensible for a client to engage its services. A target of 75% recovery (of oil contained in the material) has been set for the system being developed. Oil recovered should be good enough to be accepted by the client.

- **MOBILE:** The system has to be readily moved from one operational site to another in as little as 48 hours, notwithstanding the terrains in the Niger Delta.

- **CAPABLE:** The system should be able to process 14 tonnes of contaminated soils or 16 cubic meters of soil/oil sludge in an hour. The product of the processing shall meet the standards set by the environmental regulatory agencies. Typical mobile systems are limited to 7-9 tonnes per hour. [US – EPA]

- **CONTINUOUS:** The system should be able to operate continuously and safely.

- **SAFE:** The system should be able to operate safely without being a hazard to the environment, personnel or local community.

2.5 SITE SPECIFIC CONSTRAINTS

- **SITES ARE NUMEROUS:** These polluted sites occur all over the Niger Delta. It is estimated to be in excess of 200 sites.[SHELL NIGERIA]

- **LACK OF INFRASTRUCTURE:** The semi-urban centers in the Niger Delta have reasonably good access roads. However, the remote rural areas and farmlands in which these contaminated soils are located generally lack access roads. All-wheel drive vehicles may be the only way to get to these areas. Another way is to prepare access roads whenever the treatments are to be done. The tank farms however, have adequate access road and facilities.

- **LACK OF UTILITIES:** For the same reasons, the areas lack electric power and potable water. Whatever treatment system to be developed will have to be self-sufficient in these.

- **LEVEL OF CONTAMINATION:** This has been shown to vary from place to place. Tests have shown that some soils have up to 30% oil while others have as low as 10%. The contaminant in all cases is crude oil and/or its products. In some other locations, the crude oil was still present after a depth of 3 meters. This was the deepest sample point.

- **SOIL TYPE:** The soil has high moisture content, being in the low lying coastal plain, as well as in one of the highest rainfall zones of the world. It is relatively non-clayey and has very little silt content.

- **COMMUNITY RELEVANCE:** The area has, over time been neglected by the Government. This has led to antagonism by the locals. Secondly, the educational level of indigenes in the area is relatively high. There is therefore, awareness among the people.

- **TYPE OF CONTAMINATION:** The contamination to which this project work seeks a solution, is that caused by crude oil on the soils

down to the vadose zone. The other material that causes contamination in this area is tank-bottom sludge.

- **CLIMATE:** The average ambient temperature in the Niger Delta is not lower than 30 degrees Celsius. The tendency is that volatile components of crude oil, which are present in a contaminated site would tend to vaporize on a hot day thereby creating dangerous ignitable mixtures with air.

- **TECHNOLOGICAL LEVEL:** Due to the rather low level of technological advancement in Nigeria, any sophisticated treatment system operating in the Niger Delta will be largely unreliable.

3.0 LITERATURE REVIEW

3.1 GEOGRAPHY AND HISTORY

Nigeria is situated in West Africa, on the Gulf of Guinea. It is bounded by Cameroon in the Southeast, Chad in the Northeast, Niger to the North, and Benin to the West. These boundaries are a relatively recent creation. With the exception of a few hills, rivers, and Plateau areas, no major natural boundaries exist, apart from the Atlantic Ocean to the South. However, the terrain is often difficult, with forest and swamps in the Southern zone, and thus rivers and their tributaries form the natural arteries of communication.

Nigeria is now the most populous nation in Africa, with a population estimated at over 150 million. It has long been one of the most prominent in terms of culture and civilization. At various times in its history, some of the tribes have been the sites of civilizations counted amongst the most powerful and prosperous on the continent, with consequent flowering of art and sophisticated craftsmanship in many fields.

Nigeria is a Federal Republic, although it was once part of the British Colonies in Africa. The capital used to be Lagos. Before a more centrally placed Federal Capital was constructed at Abuja. With a land area of over 920,000km², Nigeria ranks as one of the most important nations in the world. It is known to be host to the largest group of the black race.

The Niger Delta region of Nigeria is regarded as the third largest mangrove forest in the world, an area without land for farming or any resources needed for the development of large states (until the discovery of petroleum in the 1950s) [SHELL NIGERIA, NNPC]

The Niger Delta a complex combination of ecological zones of wetlands situated in the central part of southern Nigeria, covers an area of about 70,000km², and spreads across eight of the 36 Nigeria states. These are Delta, Bayelsa, Rivers, Edo. Akwa Ibom, Ondo Abia and Imo. It is endowed with immense natural resources, particularly crude oil. See map of the area in Fig 1.

The process of the formation of the present Delta started about 75,000 years ago, and over the centuries, accumulation of sedimentary deposits washed

down the Rivers Niger and Benue, resulting in the vast flood plain there is today. The present coastal formation consists of a chain of barrier islands interspersed by river estuaries, giving the Delta a shape like a bird's foot. The population of the Niger Delta is about seven million people, and is growing at about 3% a year [SHELL NIGERIA]

British shipping had been paramount in the Delta, and when British slave trade was abolished in 1807, the merchants of the delta city-states quickly adapted themselves to offering palm oil as an alternative to slaves. Britain's Industrial Revolution had occasioned a growing demand for vegetable oils as lubricants and for the manufacture of soap, and the new Lancashire cotton industry was producing in quantity a commodity with which palm oil might be readily purchased. About nine-tenths of British trade was initially with the Niger Delta. Africans of the delta were much quicker and more successful in developing an export trade in palm oil than those of other coastal regions. One reason was simply that the palm oil was not easy to transport in quantity, and its value was not high in proportion to its bulk. Canoe transport was thus easier and cheaper than head-loading or cask rolling, and the delta afforded a ready-made system of waterways. But its hinterland also has an unusually dense population in a relatively poor agricultural environment, and therefore had both a greater need to exploit the semi-mild palm trees than was usually the case and more labour with which to do this, and to manufacture and transport the oil. [SHELL NIGERIA]

The Niger Delta is a vast low- lying region through which the waters of the River Niger drain into the Gulf of Guinea. Oxbow lakes, river meander belts, and prominent levees are characteristic landforms in this region. Large freshwater swamps give way to brackish mangrove formations near the seacoast. [SHELL NIGERIA]

The Niger Delta is underlain by young, soft, sedimentary rocks, with gently undulating plains, which become waterlogged during the rainy season. [SHELL NIGERIA].

Commercial crude oil exploration and exploitation started in this region in the 1950s, and spiraled into the boom years. Presently, Nigeria derives her foreign earnings principally from Crude oil from the Niger Delta. Production rates have been swinging between 2.0 and 3 million barrels daily over the past ten years.

TABLE 2.1: AVERAGE PROPERTIES OF OIL CONTAMINATED SOILS, AND TANK BOTTOM SLUDGE FROM THE NIGER DELTA. (Shell Nigeria 1996)

PARAMETER	OIL-CONTAMINATED SOIL (AVERAGE)	TANK BOTTOM SLUDGE
OIL CONTENT (%)	13.02	45.8
WATER (wt.%)	10.38	47.5
SOLIDS (wt.%)	76.6	6.7
pH	7.5	6.6
TOTAL PETROLEUM HYDROCARBON (g/kg)	139	447

3.2 NATURE AND BEHAVIOUR OF CONTAMINANTS

The major contaminants found in the Niger Delta are organic in origin (arising from crude oil and petroleum products spills and the indiscriminate dumping of oil-tank bottom sludges). [SHELL NIGERIA]

Crude oil and petroleum (a fraction of crude oil) and their products enter into soil and groundwater primarily through a few operations and through accidents. These include trucking accidents, pipeline ruptures, failure of underground storage tanks, oil drilling and refinery operation etc. [DPR NIGERIA]

Crude oil is a mixture of chemical compunds, which are regarded as VOCs (Volatile Organic Compounds). This means that they volatilize at individual temperatures. [MEYERS, R.A; PERRY; WISE, D.L et al]

Volatilization includes the loss of chemicals from surfaces in the vapour phase, indicating that it requires the vaporization and movement of chemicals from a surface into the atmosphere above the surface, giving rise to emissions into the air. [WISE, D.L. et al; PAGE, G.W; RISER-ROBERTS, E.]

The management of hazardous wastes (e.g. contaminated soils, and tank bottom sludges) involves many operations that can result in air emissions [18]. For example, the disposal of hazardous wastes in landfills may release volatile organic compounds (VOCs). [RISER-ROBERTS, E.]

Land treatment facilities also give rise to emissions due to volatilization [20], as the materials volatize and diffuse upward through the soil. Results from a land treatment facility demonstrated that hazardous oily wastes from a refinery were being biologically degraded, transformed, and volatilized in the soil. [WISE, D.L; PAGE, G.O]

Gases may also be generated by reactions in the soil subsurface. Aerobic and anaerobic biological activity may decompose organics to produce methane, hydrogen sulfide, carbon dioxide, or other gases, which bubble up carrying volatile materials to the surface. The addition of microorganisms to initiate aeration of the soil for stimulation of biodegradation would also increase emissions, if gases were produced. [RISER-ROBERTS, E.]

Liquid contaminants (like those arising from oil spills) are sometimes retained in the soil pores, depending on the solubility of the organic compound, the texture of the pore size distribution. For any spill with volatile components, a vapour phase will evolve above the dissolved phase, as it migrates through groundwater. [RISER-ROBERTS; PAGE, G.W; WISE, D.L.]

It is relatively easy to describe the fate of liquid hydrocarbons in soils in qualitative terms. It is clear that volatile petroleum products such as gasoline, experience considerable loss by evaporation; normal alkanes are subject to fairly rapid biodegradation; aromatic hydrocarbons, particularly those of lower molecular weight are very susceptible to dissolution into water and may thus cause contamination of water supplies in the locality [RISER-ROBERTS, E.]

Similar to water, petroleum and petroleum products, which are released in bulk quantities at the soil surface, can penetrate through the soil surface. If the released quantity is large, downward migration occurs with all soil pores being saturated with the contaminants. The nature of the soil however plays a major part in the extent of migration possible. [RISER-ROBERTS, E.; WISE, D.L.]

As a mass of liquid hydrocarbon migrates beyond a unit mass of soil, a small amount of the total hydrocarbon mass will remain attached to these soil particles via capillary forces and are referred to as **residue saturation**. (WISE, D.L.)

The fate of a mixed organic material applied to the soil surface, or introduced into the soil profile, depends on an interesting and complex combination of interactive processes relating to the nature of the material, the manner of its application, the fundamental nature of the soil, and its transient state at the time and place of interest. The chain of sequential simultaneous processes undergone by crude oil/hydrocarbon contaminants in soil may include:- [WISE, D.L; RISER-ROBERTS; PAGE,W]

- Volatilisation of the lighter components at the soil surface with consequent, possibly temporary pollution of the atmosphere, or transfer via the atmosphere.

- Runoff over the soil surface, driven by gravity and effected by the surface configuration and possibly by rainfall, with consequent contamination of nearby surface waters or concentration in surface depressions.

- Adherence of the heavier components to the soil surface, possibly resulting in clogging and hydrophobization of the soil.
- Infiltration into the soil proper.

- Downward and lateral flow within the unsaturated zone of the soil profile.

- Retention above layer interfaces within the profile.

- Retention in soil pores and attachment to soil grains, as well as to organic matter.

- Volatilization and vapour diffusion within the soil and out of the surface, or possibly movement of that vapour (if its vapour density is greater than that of air) downward within the unsaturated zone, and possibly re-dissolution in the groundwater at the water table.

- Chromatographic separation of components within the profile, resulting in a selective migration of lighter and less viscous components.

- Partial dissolution of soluble or emulsifiable components within the water phase of the soil.

- Degradation resulting from both non-biological (ie chemical) and biological processes.

- Internal drainage or leaching from the soil, either within or alongside the water phase toward the water table.

- Mounding over the water table, possibly including convergence in cones of depression or drawndown regions at wells or streams.

- Penetration into the aquifer of the soluble and denser components.

- Dispersion and further migration with the aquifer and eventual appearance in the water supplies.

The behaviour of hydrocarbons in soil is affected by the nature of the soil, and among the properties and conditions of the soils, which affect the flow regime, are the following:- [KOSTECKI, P; RISER-ROBERTS,E]

- ***Soil type/texture:*** Migration in coarse texture (ie in sandy and gravely soils) is generally faster than in fine texture (silty or clay) soils, which are more likely to attenuate and retain contaminants, and prevent them from reaching groundwater. Furthermore, such dynamic parameters as permeability, diffusivity (both to the vapour phase and to the liquid phase) are all texture dependent.

- ***The vertical uniformity or non-uniformity of the soil:*** Layered soils are more likely to retard migration in the profile, than are uniform profiles. Since the latter are rare, we almost always must deal with layered profiles.

- ***The configuration of the soil layers:*** Horizontal layers within concave troughs or depressions are more likely to retain perched bodies of the contaminating fluid, whereas slanted or sloping layers

may direct the contaminant toward wells or spring serving water supplies.

- ***The depth of the water table:*** This determines the opportunity, time and space for retention and degradation of the contaminant prior to its penetration into the aquifer.

- ***The structure of the soil:*** It is a common feature of field soils that some have fissures cracks or channels, possibily due to roots or burrowing animals. These can serve as preferred pathways, allowing transient streams of pollutants to spurt rapidly toward groundwater, thus by-passing the greater volume of the vadose zone, and evading its filtration and degradation mechanisms. Even in the absence of such channels, the structural aggregation of soils induces faster flow through the inter-aggregate macropores than within the intra-aggregate micropores where potential pollutants might otherwise be retained.

- ***In addition, there is the possibility of unstable flow,*** a seemingly anomalous phenomenon, only recently recognized. Apart from flow in macropores or fissures, which are detectable pre-existing features in the soil profile, there is an occasional tendency for flow to concentrate in tongue-like streams or convergent currents (often called “fingers”), which generally begin at the transition from fine textured to coarse-textured layers, again by-passing or short-circuiting the greater volume of the vadose zone, and allowing direct transmission of contaminants to the water table. Such streams do not follow any particular discernible feature in the profile, but are spontaneous constrictions of the flow field that seem to occur whenever the flow velocity accelerates with distance.

- ***Soil moisture:*** Initial soil wetness and the vagaries of subsequent rainfall have an obvious effect on the pattern and migration of organics in the soil, since these organics co inhabit the same network of pores and hence interact with the water initially present. There is a mutual interference between water, the wetting liquid, and organic liquids, which are non-wetting. The latter are relegated to the interiors of the larger pores, whereas the smaller pores in the necks, between grains, as well as surfaces of the grains themselves, are occupied by water, which has a greater affinity to the mineral surfaces (water being a polar liquid).

The field-scale, aerial, or special variability of basic soil properties, and of the transient conditions of the soil, strongly affect the pattern of migration of an introduced contaminant, depending on the particular time and place of its introduction. Among the properties of the invading material that affect the pattern of their movements and transformations within the soil are the following:- [KOSTECKI, P; et al]

- Volatility and vapour density
- Solubility or miscibility in water (some material are miscible in all proportions, and others have a solubility product or limit so that only so much can be carried in the water stream).
- Viscosity.
- Density.
- Uptake by or toxicity to microbes or vegetation.

These affect the pattern of movement, chemical reactivity, microbial degradability, adherence to mineral solids and interactivity with soil organic matter. Most of these properties are dependent on temperature and moisture and hence on location and season. [KOSTECKI, P. et al]

Hydrocarbons are complex mixtures of chemicals with widely varying physical-chemical properties. When spilled on soil, the environmental behaviour of these substances is controlled by a number of processes. For instance, a petroleum product can migrate through soil as a separate immiscible phase until it is completely redistributed in the vadose zone, until it reaches the water table. Redistribution is controlled by the volume of the spill, the viscosity of the product, the characteristics of the soil, and the depth to the water table. During and following redistribution, water percolating through the soil can dissolve soluble components from the immiscible phase and subsequently leach these components to groundwater. The more volatile components of the spill can also evaporate into the air-filled voids in the soil and subsequently migrate through vapour diffusion. Dissolution, degradation, and evaporation of components from the hydrocarbon cause the spill to weather. [KOSTECKI, P.et al]

3.3 METHODS OF TREATMENT

Many methods exist for the treatment of oil-contaminated soils. These methods are sub-divisible into two main categories: Civil engineering based and Process based. [CIRIA, VOL. VII]. These categories are further divisible into two broad classes based on method of application: *"In-situ"* for processes applied on the contaminated site without removal of the contaminated material, and *"ex-situ"* for those applied on the contaminated material after removal from its original position.

The location, at which the treatment is effected, provides another level of classification. Treatments can therefore be either off-site or on-site. Civil engineering methods are Excavation and Containment, while Process based methods include Thermal, Physical, Chemical, Biological and Solidification Process. Each of these methods can be applied on-site, off-site, in-situ, or ex-situ. The applicability depends on the expected effectiveness and the existing constraints. [KOSTECKI, P; CIRIA VOL VII; WISE, D. L]

The various processes under each of the methods listed above are discussed in more detail under METHODOLOGY.

The US EPA has been mandated by Section 1.21 (b) of the Comprehensive Environmental Response, Compensation and Liability Act [CERCLA] to select remedies that "utilize permanent solutions and alternative treatment technologies or resources recovery technologies to the maximum extent practicable, and to prefer remedial actions in which treatment "permanently and significantly reduces the volume toxicity or mobility of the pollutant and contaminants as a principal element. [US-EPA;CIRIA, VOL VII; CORBITT, R.A]

Process based methods are applied to solid once he have been removed from the ground. [CIRIA, VOL VII]. They may be applied on-site or removed to a central treatment facility (off-site) for processing.
On-site, Ex-situ treatment systems have the advantage of speed of delivery as well fast response to variations in the quality excavated soil [CIRIA, VOL VII; US EPA].

Ex-situ processes require an excavation/pre-processing step for effectiveness. Such integration of processes is common but usually site specific.

The selection of appropriate excavation equipment and pre-processing equipment is also site specific and has a high impact on effectiveness of entire remedial action. [CIRIA, VOL V]. These equipment are also utilized in the replacement of the treated soil in the evacuated zones. [RULKENS, W.H]

Treatment costs is a major issue considered in assessing various treatment methods. These are affected by soil characteristics, remediation objectives, volumes to be treated and the location of the treatment facility [CIRIA, VOL V]. Research and development efforts for existing systems have concentrated, worldwide, on reducing energy consumption.[CIRIA, VOL VII]. Costs, such as processing cost and maintenance costs have been known to be main drivers in profitable winning treatment projects rather than technical edge and permanence of solution [ACHARYN, P].

Systems which effectively recover useful components from a contaminated soil matrix will therefore be advantageous.

4.0 DEVELOPMENT OF TREATMENT METHODS

4.1 METHODOLGY FOR ENTIRE WORK

The work on this process development will be done in the following order: -

- Identification of the problems.
- Review of previous and current efforts at solving the problem.
- Review of internationally available techniques/methods of solving the problem.
- Identification of specific constraints that exist in the Niger Delta.
- Selection of remedial method(s), which will optimally solve the problem. This step will be aided by basic materials- characterizing experiments. It will also be carried out using procedures set out by CIRIA [CONSTRUCTION INDUSTRY RESEARCH AND INFORMATION ASSOCIATION)- CIRIA VOL I].
- Creation of a process, which will use the selected strategy.
  This will be carried out using established steps of Process design.
- Detailed Process and Equipment design which will finely establish the process and equipment. Here, the operating and capital costs of the project will be estimated. Basic qualitative HAZOP (Hazards And Operability Studies) studies will be carried out in addition to whatever Process simulation studies that can be done.
- A pilot plant of the system will be designed. This will be further aided by bench top tests on the contaminated soils and sludges to establish operational characteristics.
  Fabrication of the designed pilot will be carried.
- A series of tests and experimentation using the pilot plant will be done to establish the following: -
  - Operability.
  - Efficiency/Effectiveness.
  - Resource Recoverability.
  - Reliability.
  - Controllability.
  - Test all aspects of the design targets.
  - Conclusion of the research work on successful implementation of the above.

This entire sequence of activities is tabulated in the simplified flow chart of Fig 5. Identification of the problem and constraints as well review of previous and current efforts have been carried out and given in previous sections of the write-up.

4.2 BASIC EXPERIMENTS ON CONTAMINATED MATERIALS

Samples were collected from six contaminated sites in the Niger Delta and from two tank farms belonging to two of the major oil exploration companies operating in the region. The samples were tested for the following parameters in accordance with ASTM procedures:

a. Oil Content (Total Hydrocarbon – THC)
b. Water Content
c. Solids Content (Sand, clay and silt)
d. pH

The results are given below in table 4.

TABLE 4: SOILS TESTS RESULTS

SAMPLES/ PARAMETERS	A	B	C	D	E	F	SPDC SLUDGE	ELF SLUDGE
Moisture Content	18	17.3	19.4	18.5	18.7	17.1	52.7	19.3
Oil Content	11.5	14.3	19.7	11.7	17.3	12.5	26.4	14.9
pH (approximate)	7	7.5	7.0	7.3	7.3	7.3		
Solid Content	70	68	60.4	68.3	63.1	69.2	20.5	65.7

Notes:
a). Samples were collected during dry season
b). Samples were taken from a maximum depth of 1.5m
The sites are Obigbo, Elelenwo, Ebubu, Ogoni I & II and Isoko (Afiesere).

4.3 SELECTION OF REMEDIAL/TREATMENT METHODS

The aim here is to select innovative treatment technologies which could be modified and adapted to suit the requirements set out for the project. Innovative treatment technologies are those chemical, biological or physical processes applied to contaminated materials t0 permanently change their condition but which are newly invented, tested and used for treatment of contaminated materials but still lack enough information about their cost and how well they work to enable good prediction of their performance under a variety of operating conditions. [US-EPA, treatment technologies].
The selection procedure is in accordance with that set out by CIRIA, which attempts to consider all issues relevant to the selection of remedial methods. It has been described as analogous to those used in the UK to identify the Best Practical Environmental Option (BPEO) for pollution control purposes. [CIRIA, VOL III]. The protocols of the United States Environmental Agency (USEPA) were used as guide in the initial preparation of the CIRIA procedure. This selection process is shown schematically in Figure 5 while the broad range of treatment method is shown schematically in Figs 6 & 7.

The six basic steps involved are:

a. Establish remedial action objectives and identify site-specific constraints.
b. Identify, evaluate and select specific remedial methods appropriate for each medium (soil and sludge).
c. Integrated selected methods to produce a number of alternative strategies.
d. Check that alternative remedial strategies continue to offer the necessary degree of protection and remain practical.
e. Appraise alternatives.
f. Select preferred strategy.

4.3.1 REMEDIAL ACTION OBJECTIVES

The objectives of the treatment/remedial activities being developed were set as follows:

a) **CONTAMINATED RELATED**: The contaminated soils and sludges should be treated to contain no more than 30ppm total hydrocarbon as stipulated by the Department of Petroleum Resources (DPR) of the Nigeria Ministry of Petroleum. [DPR NIGERIA].

b) **MANAGEMENT RELATED:** The soils are to be treated within a specific budget and time span with consideration for the possible reuse of the soils in their original position. A treatment budget of $100/tonne has been set. This is approximately 40% of the treatment cost that applies using foreign based treatment systems, which currently operate in Nigeria at $240-260/tonne. [SHELL NIGERIA; EXXON MOBIL]. Another objective is to recover no less than 60% of the oil contained in the material. The system should be totally independent in terms of energy.

Summary statement of the objectives is therefore as follows:-
To treat oil contaminated soils down to a contaminant level of 30ppm at treatment cost rates less than $100/tonne while recovering at least 60% of the oil contained in it and not procuring any energy from external sources.

4.3.2 SITE SPECIFIC CONSTRAINTS

- **SITES ARE NUMEROUS:** These polluted sites occur all over the Niger Delta. It is estimated to be in excess of 100 sites.

- **LACK OF INFRASTRUCTURE:** The semi-urban centers in the Niger Delta have reasonably good access roads. However, the remote rural areas and farmlands in which these contaminated soils are located generally lack access roads. All-wheel drive vehicles may be the only way to get to these areas. Another way is to prepare access roads whenever the treatments are to be done. The tank farms however, have adequate access road and facilities.

- **LACK OF UTILITIES:** For the same reasons, the areas lack electric power and potable water. Whatever treatment system to be developed will have to be self-sufficient in these.

- **LEVEL OF CONTAMINATION:** This has been shown to vary from place to place. Tests have shown that some soils have up to 30% oil while others have as low as 10%. The contaminant in all cases is crude oil and/or its products. In some other locations, the crude oil was still present after a depth of 3 meters. This was the deepest sample point.

- **SOIL TYPE:** The soil has high moisture content, being in the low lying coastal plain, as well as in one of the highest rainfall zones of the world. It is relatively non-clayey and has very little silt content.

- **COMMUNITY RELEVANCE:** The area has, over time been neglected by the Government. This has led to antagonism by the locals. Secondly, the educational level of indigenes in the area is relatively high. There is therefore, awareness among the people.

- **TYPE OF CONTAMINATION:** The contamination to which this project work seeks a solution, is that caused by crude oil on the soils down to the vadose zone. The other material that causes contamination in this area is tank-bottom sludge.

- **CLIMATE:** The average ambient temperature in the Niger Delta is not lower than 30 degrees Celsius. The tendency is that volatile components of crude oil, which are present in a contaminated site would tend to vaporize on a hot day thereby creating dangerous ignitable mixtures with air.

- **TECHNOLOGICAL LEVEL:** Due to the rather low level of technological advancement in Nigeria, any sophisticated treatment system operating in the Niger Delta will be largely unreliable.

4.3.3 REMEDIAL/TREATMENT METHODS AVAILABLE

Remedial/Treatment methods which are traditionally applied to contaminated soils are described below. The table 5 summarizes the merits and demerits of the various methods that can be applied to the soils and sludge of Niger Delta.
Any of the methods listed will need to be applied to the soil ex-situ and on-site.

4.3.3.1 BRIEF DESCRIPTIONS OF TREATMENT PROCESS FOR OIL-CONTAMINATED SOILS

4.3.3.1.1 STABILIZATION AND SOLIDIFICATION

Stabilization / solidification methods change the physical state of a contaminated material and/or reduce the availability of contaminants to potential targets through chemical stabilization and by containment within a solid, low permeability product. While stabilization involves the addition of reagents to reduce the fluidity of the containment and prevent access by external mobilizing agent. (WISE, D. L et al; CIRIA VOL I).

Stabilization / solidification process can be grouped into three:

a) Process that use cementitious binders.
b) Process that use organic binders.
c) Process that use other system such as sulphur.

The main limitation of the stabilization / solidification methods of treatment is that they do not destroy or reduce the contamination level.

4.3.3.1.2 CHEMICAL TREATMENT METHODS

Chemical treatment methods make use of chemical reactions such as oxidation – reduction, hydrolysis and neutralization to treat contaminated soils. They are used to: -

- Destroy contaminant
- Reduce their toxicity
- Increase their solubility
- Decrease their solubility
- Increase susceptibility to other form of treatment.

Chemical treatment methods may have some of the following effects on soil properties. (CIRIA VOL III; CORBITT; US-EPA)

a) Natural soil process may be inhibited.
b) Fauna in the soil may be adversely affected.
c) Soil structure and permeability may be adversely affected.

Nutrients may be demobilized.

4.3.3.1.3 BIOLOGICAL TREATMENT METHODS

These rely on the natural metabolic process of living organisms e.g. bacteria, fungi and even plants, to destroy or to convert contaminants to a less toxic form. The contaminant provides energy and carbon for the organism, while nutrients and oxygen are supplied to the contaminated zone for aerobic bioremediation. For anaerobic cases, other substances such as Nitrate or Sulphate take the place of oxygen.

Two main methods for the existing treatment of contaminated soils are:

1) Treatment beds
2) Bioreactors.

Biological treatment methods have been applied to contaminated soils, and sludges over the past 15 years. If the major limitation such as speed of treatment can be overcome, the method offers significant advantages in term of level of destruction of contaminants; absence of harmful by-products, low energy consumption and relative low cost. (IBIDAPO, T. A. et al)

4.3.3.1.4 PHYSICAL METHODS

Physical treatment methods seek to immobilize wastes, detoxify them or render them less harmful. These are done by manipulating the physical properties of the wastes, while the chemical characteristics remain constant. In most cases physical treatment methods produce residue that require further treatment prior to disposal. (CIRIA VOL VII)

Some established physical treatment methods are: -

a) Vacuum Extractor and Steam Stripping: This is used to extract volatile contaminants from the vadose zone.
b) Soil Washing: Here water is used as the separation medium.
c) Solvent Extractor: Non-aqueous solvents are used to effect the separation.
d) Electro Remediation: Electrical processes are used to remove the contaminants.

4.3.3.1.5 THERMAL METHODS

These treatment methods use heat to remove or destroy the contaminants. These main types of thermal treatment that are commercially applied to contaminated soils are:

1. THERMAL DESORPTION: Here the contaminant is removed from the soil matrix at relatively low temperature and then processed downstream of the system.

2. INCINERATION: Contaminants are destroyed at high temperatures.

3. VITRIFICATION: Here, very high operating temperatures are used to destroy some contaminants and trap others in glassy phase, which offers extreme resistance to leaching.

Thermal Desorption and Incineration tend to go on in the same facilities, because in a typical operation, thermal desorption will occur partially in the colder part of the kiln whereas incineration of desorbed gases from a thermal

desorption system is usually done in a downstream incinerating device for destruction of volatile organics.

The main limitations of thermal treatment methods include the following:

a. Metals could volatilize in the system and foul flue gas treatment systems.
b. Contaminated materials need to contain at least 20% solids for conveyance purposes.
c. Feed size will need to be restricted for the optimization of heat transfer.
d. High moisture content of contaminated material adversely affects energy requirement of the system.
e. Costs of such systems are usually high.

TABLE 5: SUMMARY OF MERITS AND DEMERITS OF TREATMENT METHODS

METHODS	ADVANTAGES	DISADVANTAGES
EXCAVATION/ CONTAINMENT	Quick, economical solution. Cheap.	Not permanent solution. Does not treat. Questionable long-term reliability.
SOLIDIFICATION/ STABILIZATION	Usable for particular contaminants. E.g. PCBs*. Largely suitable for inorganic/metallic substances. Relatively cheap.	Not suitable for organics. Uneven permeation in in-situ application. Effectiveness is generally low.
BIOLOGICAL	Natural process. Relatively inexpensive. Products are harmless. Targets are specific. In-situ applicability. Permanent destruction of contaminant.	Some compounds are recalcitrant. Degradation is slow. Hydrophobic substances may not be bioavailable. Prolongs clean up. Potentially hazardous by product. Predictability of treatment

		is low.
CHEMICAL	Could be used to pre-treat contaminant. Could be used to reduce toxicity of the contaminant. Could be used to deal with specific, difficult to treat contaminant. E.g. PCB.	Specific to contaminant. Limited applicability. May affect soil chemistry and re-use. Effectiveness not yet demonstrated. Predictability of treatment is low.
PHYSICAL (VARIOUS)	Comparably cheap.	Requires another method to complete. Nature of feedstock affects process. Separation coefficient may be unfavourable. May severely affect environment.
THERMAL	Very effective against hydrocarbon contaminants. Flexible operating parameters. Could be made mobile. Could achieve DRE** of 99.9%.	Metals volatilize at temperatures of operation. Better suited for solids. Moisture affects energy demand. Silt and clay affect dust generation. Highly energy intensive. Costly to run. Requires elaborate feed preparation.

***PCB:** Polychlorinated Biphenyls. ****DRE:** Destruction and Removal Efficiency

Thermal Separation Technologies include Thermal Desorption Soil vapor extraction etc., while Thermal Destruction Technologies include Incineration and pyrolysis and one example of a Thermal immobilization technology is Vitrification.

Thermal treatments are the "presumptive remedies" for sites similar in characteristics to the Niger Delta contaminated soils. "Presumptive Remedy" is defined by EPA as a technology, EPA believes, based on its past experience generally will be the most appropriate remedy for a specified type of soil.

For on-site, ex-situ treatments, there is need to excavate the soil and prepare the feed prior to treatment. This excavation being a method of treatment will therefore need to be combined with the thermal methods for effective operations.
The three thermal methods are equally suitable in terms of effectiveness and time. However, based on the desire to have the soil re-usable in their original locations, Vitrification and Incineration will be inadequate, since they will burn the soil. Thermal Desorption therefore takes the primary position followed by Incineration.

Thermal Desorption will generate off stream gases, which require further processing. Systems, which will process the gases into useful liquid, will be focused on in this project, since that is part of the Management-based objectives for the treatments. Such systems are best classified as Physical Methods.

4.4 INTEGRATION OF TREATMENT/REMEDIAL METHODS

Due to the nature of the contaminated soils and the sludges, it is obvious that no one treatment method will be adequate for the remedial action. Some methods will need to be combined to achieve effectiveness and the desired objectives.

The following possible combination of methods (remedial strategies) could be used in the treatment of the contaminated soils and sludge of Niger Delta.

SOIL MATRIX: (A)

A1; EXCAVATION, THERMAL DESORPTION AND PHYSICAL METHODS

A2; EXCAVATION, INCINERATION AND SECONDARY INCINERATION

SLUDGE MATRIX: (B)

B1; EXCAVATION, THERMAL DESORPTION AND INCINERATION.

B2; EXCAVATION, SOLVENT EXTRACTION, THERMAL DESORPTION AND INCINERATION.

B3; EXCAVATION, PHYSICAL SEPARATION, THERMAL DESORPTION AND PHYSICAL METHODS.

These strategies are shown schematically in Figure 9, while the various process flows are shown in Figures 10, 11 & 11a for strategies A1 and B3.

4.5 EVALUATION OF THE TREATMENT STRATEGIES.

The strategies are evaluated using the method set out by CIRIA. The basic steps involved are as follows:

a. Detailed description of the alternative remedial strategies.
b. Detailed evaluation of possible options against key criteria detailed.
c. Comparative analysis of the alternative strategies and selection of the preferred remedy.

Key Criteria

i. Protection and Compliance
ii. Long term performance and permanence
iii. Technical sufficiency
iv. Impact on workforce and environment during treatment practicality including time scale
v. Cost
vi. Social and community impact and acceptance
vii. Institutional acceptance

4.5.1 DESCRIPTION OF REMEDIAL STRATEGIES

Process flow diagrams of the five strategies are shown in the following pages (in Figures 10, 11a & 11b)

Strategy A1

In this combination, the contaminated soil shall be excavated, crushed and screened to a size not bigger than 40mm. The material shall then be fed via a combination of conveyors into the thermal desorption system where it will be heated to an appropriate temperature for suitable duration to effect the full vaporization of the hydrocarbon and water. The vapor generated is swept out of the chamber into a total condenser, which condenses as much of the vapor as is possible. The liquid so condensed will then be separated into oil and water. The non-condensable vapors will be adsorbed by activated carbon.
The de-oiled/treated soil will be sent to a humidifier/moisturizing unit, which uses re-cycled water from the condensers. The recovered oil is sent back to the facilities of the oil producing company.

Strategy A2
In this combination, the screened contaminated soil is fed into a direct heat incinerator where the oil is burnt off. Some of the oil will naturally escape combustion in this chamber and get carried by the flue gases into the secondary combustion chamber for destruction. No products are recovered, therefore the water that will be used for wetting the soil will have to be supplied. This strategy will not meet the part of the management objectives that require the recovery of oil.

Strategy B1
This is similar in many respects to strategy A1. The main difference is in the preparation of the feed. The quantity of recoverable fluid is bound to be higher since the sludge contains a smaller amount of solids than the oil-contaminated soils. There will therefore be a higher demand for coolant in the condensation unit.

Strategy B2
This strategy has the additional stage of solvent extraction. It will operate by using a suitable solvent to extract some of the oil from the sludge matrix. The solution of the oil in the solvent is then processed for oil recovery as well as solvent recovery. The method will certainly not remove all the oil contained in the sludge; it will be necessary that the de-oiled sludge be further treated in a thermal system for full oil removal. There is the need to purchase the suitable solvent. The presence of this solvent extraction stage will certainly increase the risks associated with the entire treatment.

Strategy B3
Physical methods could be used to remove some of the oil prior to thermal desorption activities. This is basically in order to lighten the load (thermal and physical) on the main processing system and to improve the overall efficiency of the treatment process. One such physical process is centrifuging, which could be enhanced by heating. The tailings of this process will be heavy, sand-containing component while the overflow will be largely water and hydrocarbon fluid.
Major advantage of this is the lower load on the condensers, which recover the oil. Main disadvantage is the extra cost of the physical equipment and piping. Another advantage may be possible improvement on efficiency with

respect to factors such as extent of resource recovery and degree of treatment of the sludge.

4.5.2 EVALUATION OF STRATEGIES AGAINST KEY CRITERIA

STRATEGIES / KEY CRITERIA	A1	A2	B1	B2	B3
PROTECTION & COMPLIANCE	GOOD	GOOD	GOOD	GOOD	GOOD
LONG TERM PERFORMANCE AND PERMANENCE	GOOD	POOR	GOOD	GOOD	GOOD
TECHNICAL SUFFICIENCY	GOOD	GOOD	GOOD	POOR	GOOD
IMPACT ON ENVIRONMENT	GOOD	GOOD	GOOD	POOR	GOOD
PRACTICALITY	GOOD	GOOD	GOOD	POOR	GOOD
COST	HIGH	HIGH	HIGH	V.HIGH	HIGH
SOCIAL AND COMMUNITY IMPACT	GOOD	POOR	GOOD	GOOD	GOOD
INSTITUTIONAL IMPACT	GOOD	GOOD	GOOD	GOOD	GOOD
OVERALL ASSM'NT	GOOD	WEAK	GOOD	WEAK	GOOD

TABLE 6: EVALUATION OF THE STRATEGIES

4.5.3 COMPARATIVE ANALYSIS OF THE STRATEGIES

SOILS

Strategies A1 & A2

Considering the desire to have the soil reusable in the original location for farming purposes, Strategies A2 could be judged inappropriate because of the high temperatures the soil will experience in the incineration chamber. Such high temperatures destroy the natural organics in the soil and render the soil un-usable for farming. Strategy A2 therefore scores poorly in terms of 'Long term performance' and in terms of 'Social and community impact'. Secondly A2 does not effect any recovery of the oils.

Strategy A1 therefore becomes the preferred strategy for contaminated soils.

SLUDGES

Strategies B1, B2 & B3

The residual materials that could arise from the process is reason for the poor score of Strategy B2 in 'Technical sufficiency'. These residual materials will require a secondary treatment process for them to be environmentally acceptable. Secondly, due to the need to use solvents, the impact of the process on the environment is considerably higher than that of the other two strategies. Hence its poor score there. 'Practicality', which is a reflection of the technical feasibility (construction, operation and reliability) is comparatively poor for the Strategy B2. Lastly, since the solvent extraction steps involve major equipment for material handling and solvent recovery, the relative cost of the Strategy B2 is much higher than the other two competing strategies. Strategies B1 and B3 therefore qualify for more detailed consideration.

Strategies B1 & B3

Due to the extra stage of physical treatment, Strategy B3 may seem to be less attractive than B1. However, it is easy to see that having separated reasonable amounts of the liquid from the sludge matrix up-stream of the thermal desorption unit, the thermal load on the unit will be lower. Secondly, the vapor generated by the thermal desorption unit will be smaller, translating directly into a reduced requirement for heat exchanger. This combination may easily result in increased liquid recovery, which positively affects the economy of the treatment process. It may also be possible to effect the thermal desorption at some lower temperature on account of the oil removal. This is certainly positive in the eyes of the community, as the soil can now be easily re-usable.
A proper comparison of the two strategies may only be possible with pilot plant evaluations. This, however, will be a very expensive procedure. It is worth noting that one of the factors that will enhance the physical step is heating from the sludge and that this can readily be effected using the waste heat from the combustion chamber. The heat will greatly affect the viscosity of the sludge thereby enhancing separation of the oil and water from the sludge matrix

The only real difference between the two strategies A1 & B3 is the added physical method. This method may not be very much of a variation to the physical set-up of the process. It also does not amount to any more than a fractional increase in the cost of setting up the process. On the other hand, it will definitely enhance the recoverability of the oil. Strategy B3 will therefore be adopted as the Preferred Remedial Strategy. This strategy will therefore be developed into a process. Bearing in mind the need to meet the remedial action objectives.

5.0 PROCESS DEVELOPMENT

5.1 PRELIMINARY PROCESS CREATION

PROCESS DESCRIPTION

Process flow diagrams for the preferred remedial strategy B3 are shown in Figure 11a & 11b. This is used below to describe the processes involved in the remediation/treatment activity.

The material (feed) preparation area for the treatment of soil or sludge is where the main variation exist. For soils, the contaminated soil is excavated and crushed to size, screened and fed via belt conveyors into the Thermal Desorption unit. For sludge, the material is collected, heated to enhance mobility and then pumped to the physical separation system where some of the free liquid and resulting vapor are removed and sent to the cooler. The solid off take from the physical separator will then go into the Thermal Desorption unit. In this unit (TDU) the materials (soil or sludge) experience the same thing: A volatilization of the water and hydrocarbon contained in the material. The resulting vapor is swept through a set of solids-trapping mechanism (where any solid particles being carried over by the desorbed gases are trapped) and then cooled in a condenser. Fluid from this condenser goes into a gas-liquid separator where the non-condensable gases are separated and sent out to a carbon bed adsorption chamber. The liquid separated being a mixture of oil and water is sent to an oil-water separator where the oil is recovered and pumped back to facility where it will be used to make the fuel that will power the generators. The water is taken out and treated to eliminate traces of oil and used in some aspect of the process – soil wetting, heat exchanger etc. The heat from the combustion Chamber is used to heat up the Thermal Desorption Unit.

The treated soil that leaves the Thermal Desorption Unit is essentially free of hydrocarbon and will be very hot. It is cooled in a cooling and wetting system prior to dumping in the original place it was excavated from. The flue gases generated from the combustion are sent into a set of Scrubbers where they are treated before being released into the environment.

In situations where the recovery of the oil is impractical (such as very low oil-content soils) the vapor released in the Thermal Desorption Unit will be piped straight into an After Burner Chamber for destruction of the desorbed hydrocarbons.

Vapor transport is effected by vacuum pull using a passive method such as air-ejector.

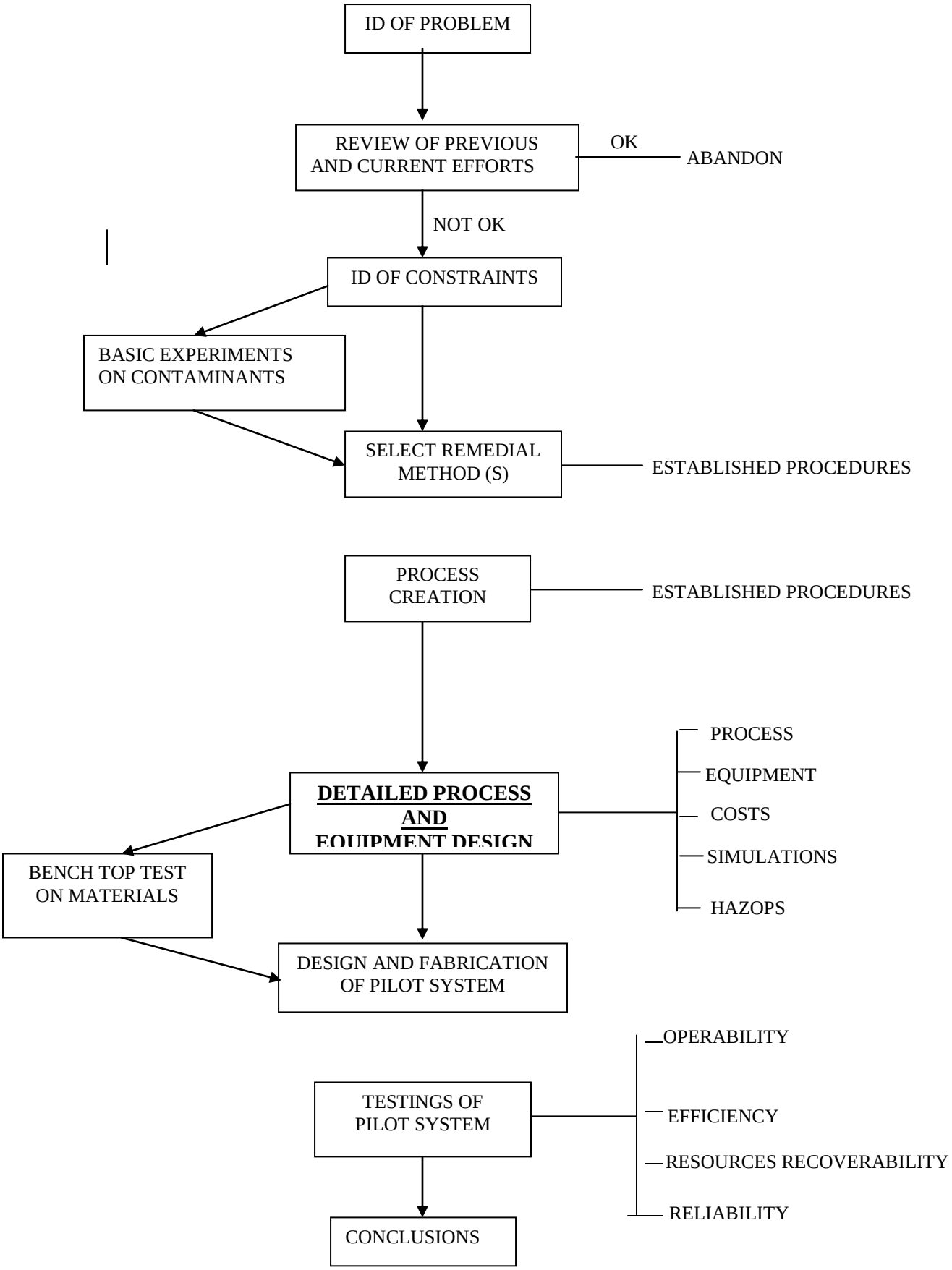


FIG 5: FLOW CHART OF METHODOLOGY (CIRIA VOL I)

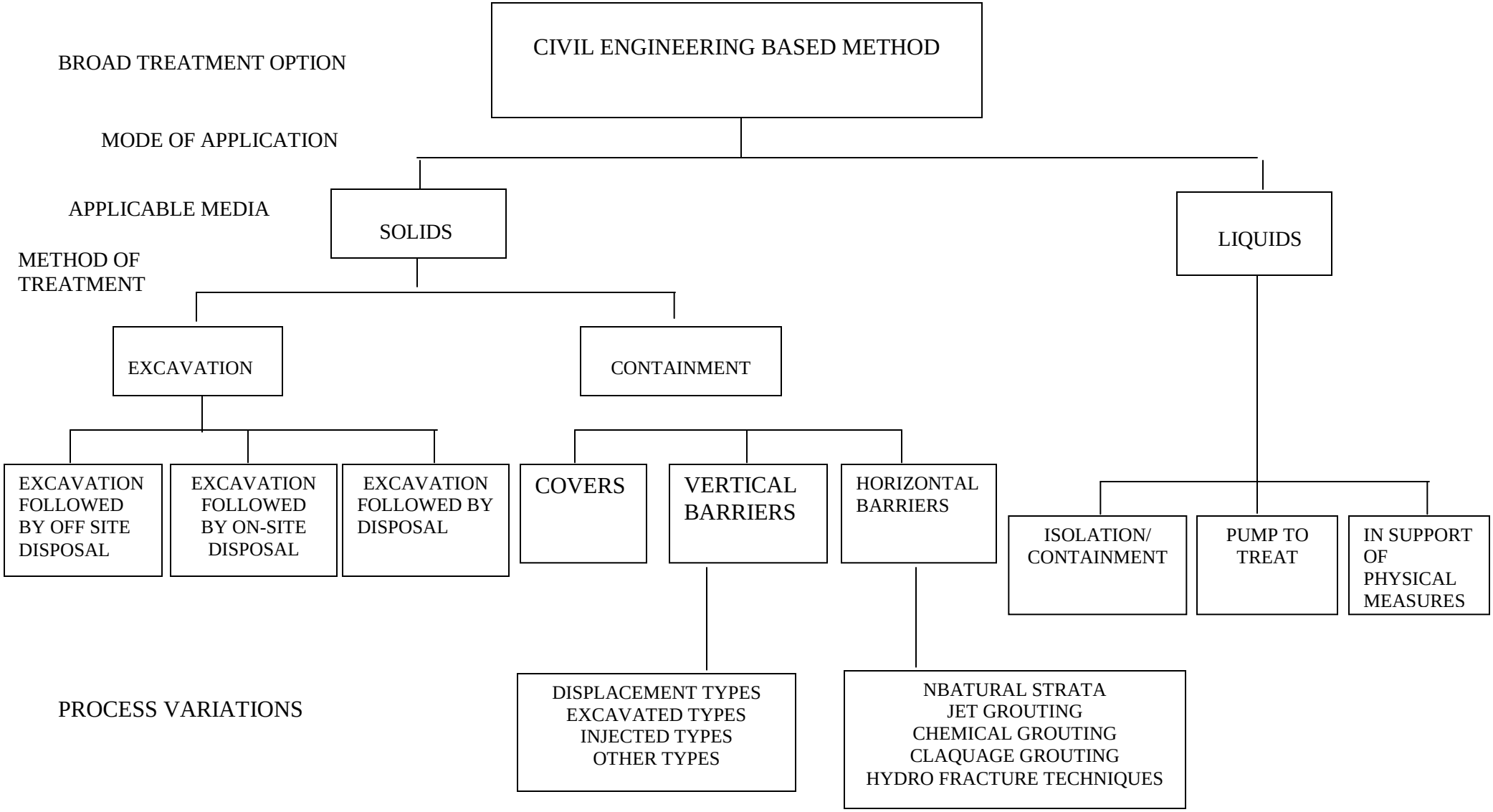


FIG 7: CLASSIFICATION OF CIVIL ENGINERING BASED REMEDIAL METHODS (CIRIA)

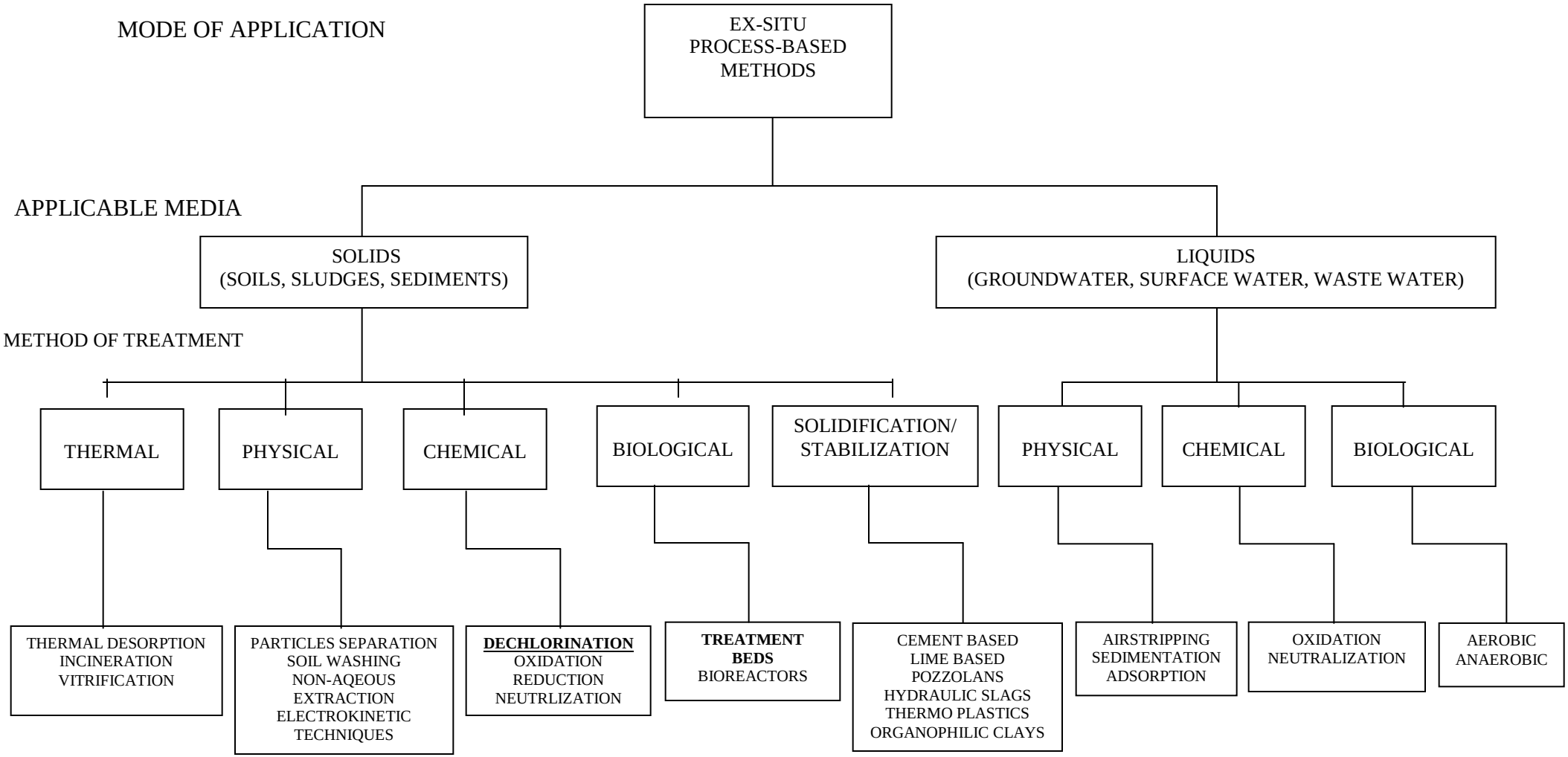
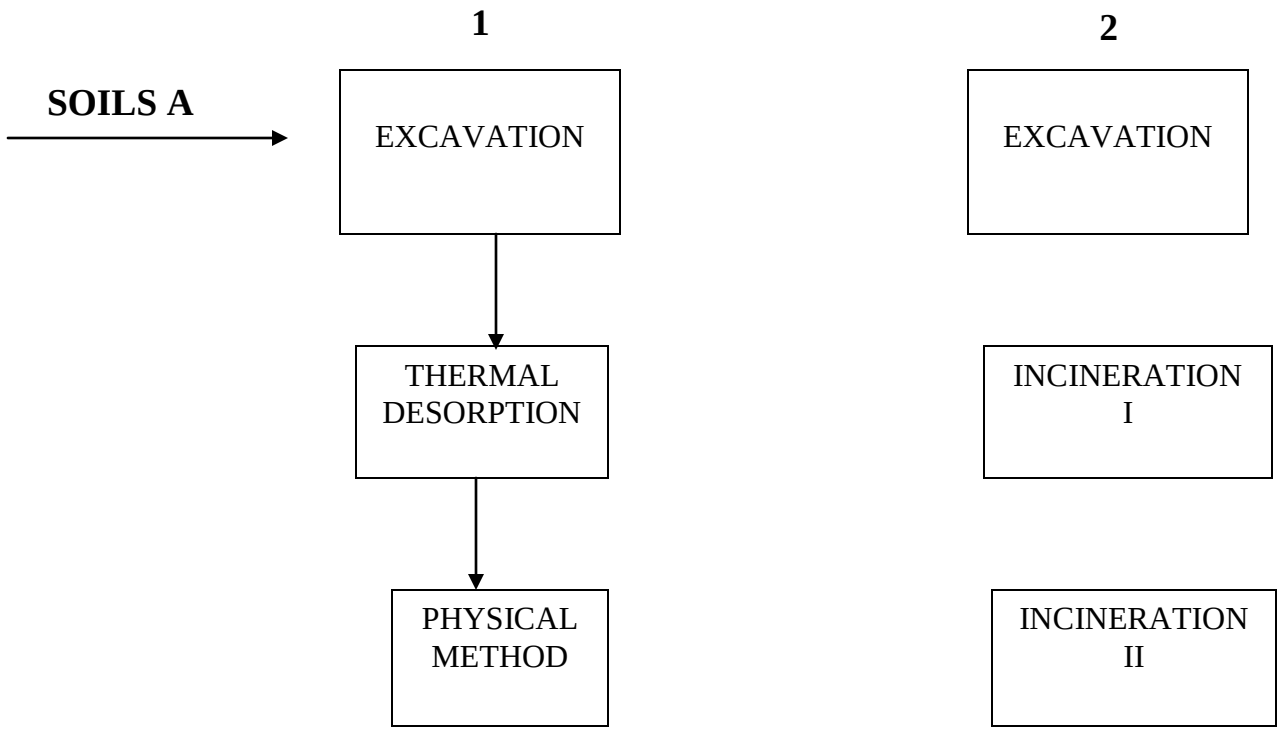


FIG 8. CLASSIFICATION OF EX-SITU PROCESS-BASED REMEDIAL METHODS (CIRIA)



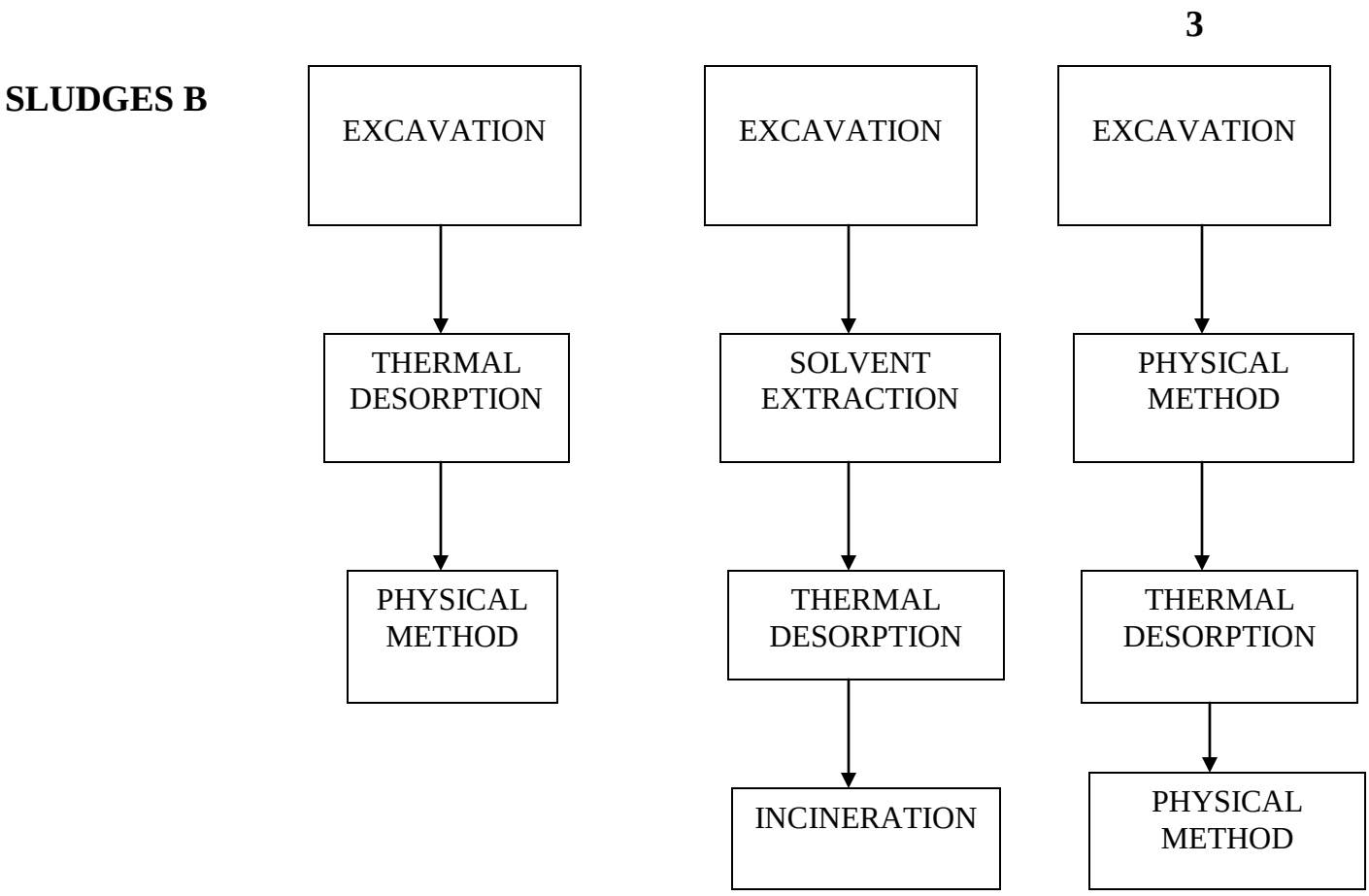


FIG.9: POSSIBLE COMBINATIONS OF REMEDIAL METHODS (STRATEGIES)

MATERIALS IN PROCESS AND THEIR STATES

A---CONTAMINATED SOILS (SOLID AND COLD)
B---DESORBED VAPOR (GAS AND HOT)
C---TREATED SOILS (SOLID AND HOT)
D---CONDENSED LIQUID (LIQ + GAS AND COLD)
E---OIL + WATER (LIQUID AND COLD)
F---NON CONDENSABLES (GAS AND COLD)
G---RECOVERED OIL (LIQUID AND COLD)
H---RECOVERED WATER (LIQUID AND COLD)
I---FLUE GASES (GAS AND HOT)
J---TREATED FLUE GAS (GAS AND HOT)
K---OIL (LIQUID AND COLD)
L---FUEL FOR BURNING AND POWER (LIQUID AND COLD)
M---TREATED WATER (LIQUID AND COLD)

B---DESORBED VAPOR when liquid recovery is not possible**
****------FACILITIES NOT REQUIRED for that situation**

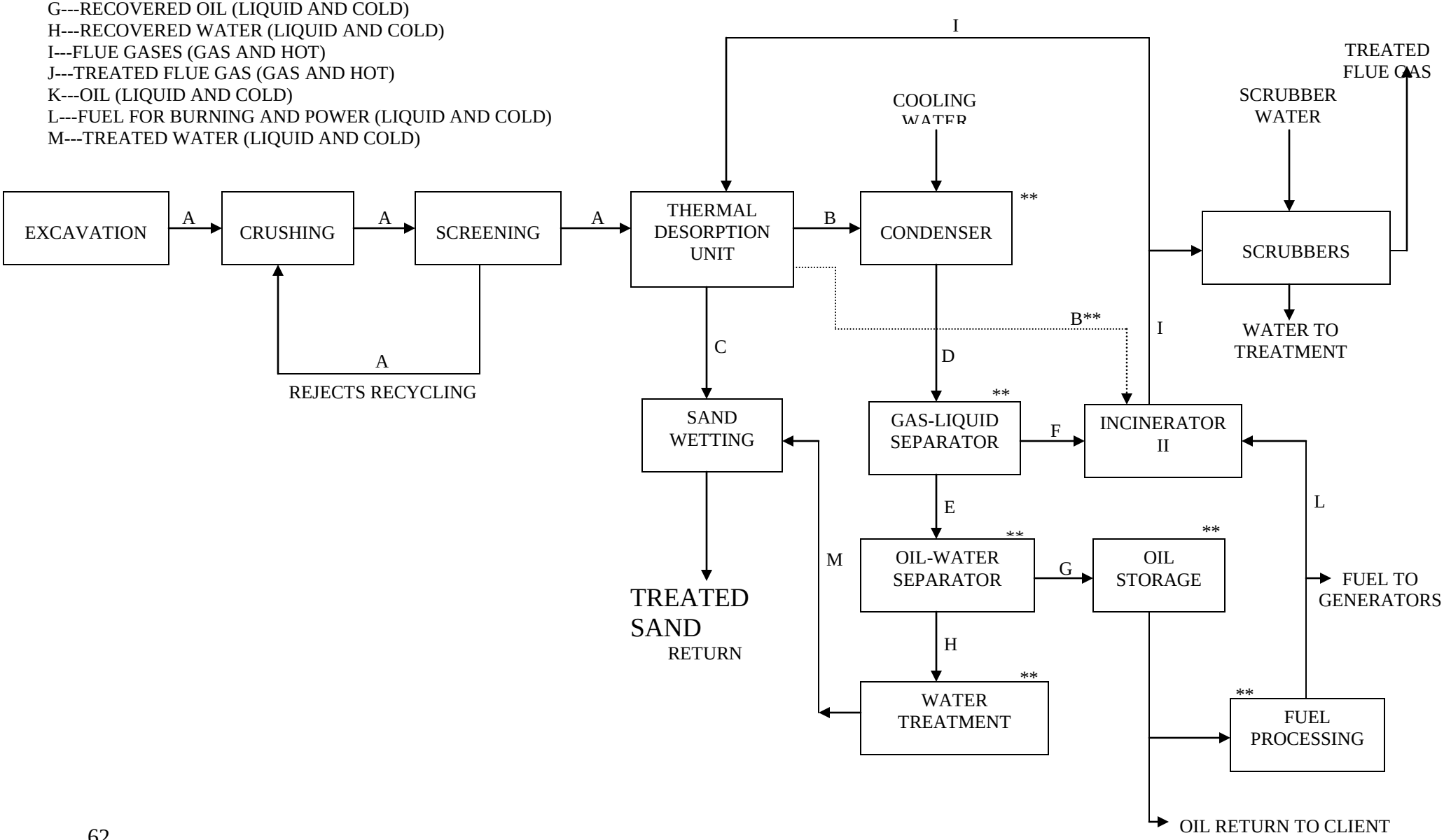


FIG.10: BLOCK FLOW DIAGRAM FOR STRATEGY A1 SHOWING MATERIALS IN PROCESS

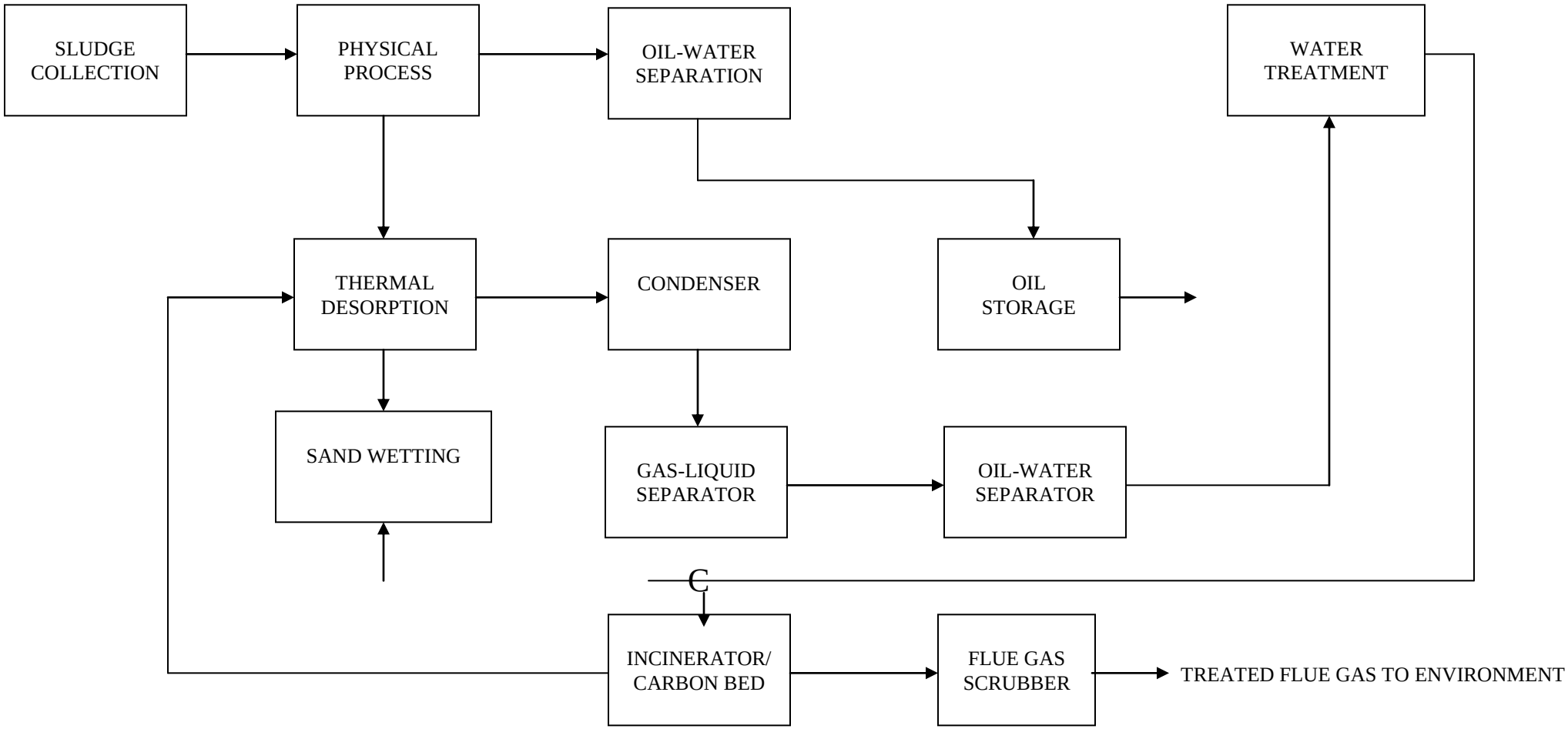


FIG. 11a: <u>REMEDIAL STRATEGY B3</u>

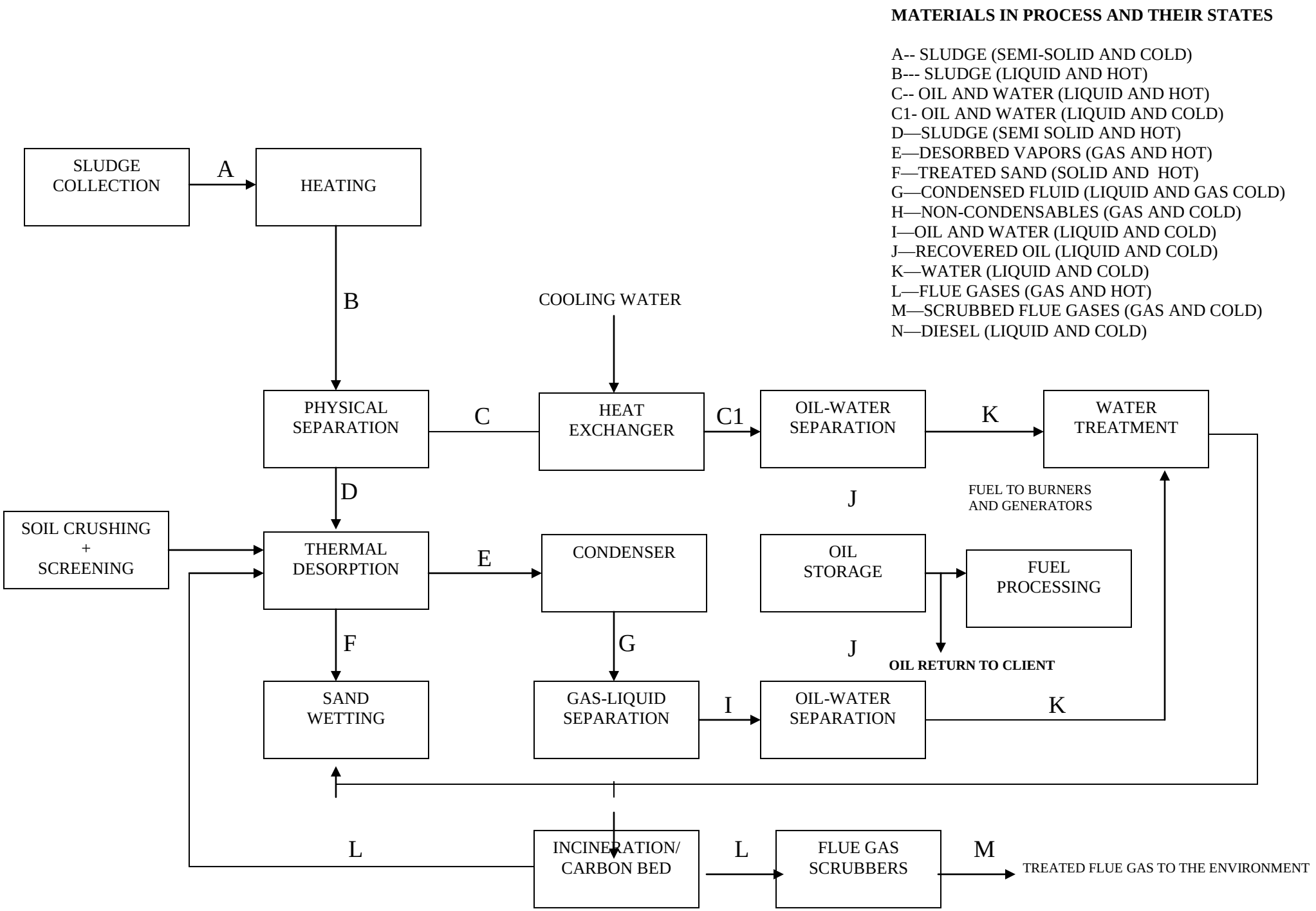


FIG. 11b: BLOCK FLOW DIAGRAM FOR STRATEGY B3 SHOWING MATERIALS IN PROCESS

5.2 DETAILED PROCESS DESIGN

5.2.1 MATERIAL PREPARATION

(a) SOILS

This basically involves the excavation of the soil, transporting of the soil and screening of the soil for feeding into the processing system. The excavator will dump the soil onto belt conveyor which feeds the vibratory screen where the soil lumps are shaken through 5cm screens. This being the optimum size for effective heat transfer inside the downstream Thermal Desorber. [FREEMANN, H.M.; US EPA; CIRIA VOL VII]

At a design processing rate of 10 tonnes per hour, the conveying system should be able to deliver no less than 167 kg of soil per minute.

(b) SLUDGE

This material is available in consistencies ranging from fluid to solid. However, they all become very fluid when heated to 80^{o}C.

It will therefore be processed for feeding into the Thermal Desorber by heating using electrical immersion heaters equipped with thermostatic control. Some vapor will be generated in this step and will be directed into the burning chamber for destruction. A pump then takes the warm fluid for additional heating through a set of heaters using the excess heat in the flue gas of the Thermal Desorption unit. Here it is heated to about 350^{0}C and flashed into the TDU. The schematic drawing of this process step is shown in figure 12a & 12b for soils and sludge respectively.

5.2.2 THERMAL TREATMENT OF MATERIALS

The main action required here is the Physical separation of the volatile and semi volatile contaminants from the soil or sludge [US-EPA]
Therefore water will necessarily leave the system with the hydrocarbon components for further separation in downstream equipment.

(a) THERMAL DESORPTION

Heating of the contaminated soil or sludge can be done directly or indirectly. In the former, oxidation of the volatiles occurs and recovery will not be an option. In the indirect heating, the vaporized contaminant can be collected and processed. Since our goal is to recover organics, our system will be indirectly heated. Heating can be done with hot oil, steam, molten salt or hot combustion gases (Flue gas) [USEPA]

The temperature at which the system operates is the primary factor that affects performance. The second factor affecting performance is the residence time of the soil or sludge at the temperature of treatment. High temperature and short residence may effect the same result as low temperature and long residence. [US-EPA; RLC TECHNOLOGIES]

Generally, the material is transported and agitated inside the system as it is being heated. This enhances the vaporization of the volatiles by exposing more materials to the hot walls of the desorber. Desorbers come in a variety of configurations. A cylindrical drum with internally welded strips which aid in conveyance and agitation is the more common type. Being easier to maintain and operate. It is however more expensive [US EPA; CIRIA VOL VII; IKEGUCHI,T;] Obviously as the soil being treated gets dry in the chamber, the agitation and conveyance actions tend to generate dust which leave the chamber with the vaporized contaminants. This is undesirable as it places extra load on the downstream equipment dedicated to processing the vapors. To minimize this dusting, the rotational speed of the chamber which effects the agitation and transport is kept low. Secondly, the internal strips (flights) are absent in the later portion of the chamber where the soil will have attained relatively dry consistency. [US EPA; CORBITT, R.A; PERRY FREEMAN, H.M]

Low temperature systems operate at temperatures ranging from 250 – 350^{o}C. While high temperature system go as high as 650^{o}C. [CORBITT, R.A.; USA EPA; CIRIA VOL VII].

Thermal desorption plant that processes between 3 and 10 tonnes/hour will have capital costs ranging from $3 and $5 million (US) [BANSAL, K.M.]

Many variations of the Thermal desorption process have been developed and are being used for treating various wastes in the Oil and Gas industry. They include; [ZUPAN; BANSAL, K.M; CORBITT, R.A]

- Indirectly heated Rotary drums.
- Hot oil processors.
- Thermal Phase separator.
- Thermal Distillation.
- Thermal Plasma Volatilization.
- Modular Thermal Processors.

The indirectly heated Rotary drum is the system we have chosen for this project as it is the one that meets with the goal of simplicity, effectiveness and reliability set for the project and which are appropriate to the environment in Nigeria. The other systems listed above are described in the Appendix.

The vapor generated in the Thermal desorption unit will need to be withdrawn from the chamber for processing. This is done usually by sweeping the chamber with a carrier inert gas or by vacuum pull. The presence of the carrier gas usually compromises the effectiveness of the condensing of the vapor.
Therefore the method of vapor withdrawal shall be by creation of reduced pressure in downstream equipment which will effect the draft of the vapor through the system. The quantity of soil or material that the Rotary Drum can hold and process is limited by its size. It is known that the optimal hold up for processing is 15% of the volume. [PERRY; CORBITT, R.A. FREEMAN; H.M].

Secondly, the need to have the entire process mobile limits the size of the desorber to what is transportable through the roads. This translates to a limitation on the capacity to treat the soil in any location. This is the reason for the secondary drying unit proposed in the design.
The aim is to have the Thermal Desorption unit process the soil partially thereby having a higher throughput per hour than its design will permit if working alone. The partially treated material will then be fed to the secondary dryer for completion.

(b) GRAVITY BED DRYER

If soils have been dried to the point where they are free flowing but still contain some oils , they can be fed to a secondary dryer which will strip off the remaining oil in a countercurrent encounter with hot flue gases. This is a direct heating activity and takes place outside the Thermal Desorption unit. The effluent gases from this will contain the remaining volatile contaminants

and will be channeled to a thermal oxidizer for destruction of all the volatile organic compounds (VOC). The performance objectives include:

- Reduction of contaminant level to target level
- Reduction of system complexity
- Improvement of overall system efficiency/throughput.

The flow of the soil being treated and the flue gas can be adjusted to give desired product temperature and oil content. Intimate contact among discrete soil particles and the hot flue gas maximize evaporative mass transfer [KIMBALL G]

The purge bin is known to be the most efficient and proven means to accomplish the desired speedy and low level ppm drying for medium – coarse-sized particles in true plug flow [KIMBALL,G; PERRY]
It will therefore be possible to treat the contaminated soil in the Thermal Desorption Unit to an oil content level of 4 –5% and use the purge bin to complete the treatment down to 100ppm oil content. This way it will be possible to process more than 50% extra capacity without compromising quality.

5.2.3 VAPOUR PROCESSING SYSTEM

(a) DUST COLLECTION

Reasonable amount of dust will leave the desorber with the volatiles. This dust will need to be removed from the stream for effective processing of the oil vapor. Of all dust catching equipment, the cyclone offers the passive ease and efficiency this project aims at. It will however not be able to remove all the dust. If a number of cyclones are positioned in series, the effectiveness is reasonably improved [PERRY; SINNOT, R.K]
The finer particles of this dust stream will be borne by the vapor stream into the downstream processing equipment.

(b) QUENCH UNIT

It is necessary that the system being developed produce its own fuel (as diesel) from the oil contained in the material being treated. Since it has some dust entrained and may also be at a much higher temperature than desirable, it is necessary to partially quench the stream with cold liquid which will knock out the remaining dust particles and cool the vapor to the upper temperature range of diesel. [ULLRICH , R]. Naturally the run-off from the quench unit will need to be cooled to ambient temperature, filtered and stored. This oil is part of the oil that is returnable to facility owner and also be used for combustion purposes at the site.

(c) DIESEL MAKING UNIT.

A partial condenser and a basic fractionating column will be used to process the vapor into diesel. This diesel fraction will be cooled and stored for use.

All the remaining vapor will be totally condensed and sent into tanks for separation of the water component. This water component will be passed through carbon bed filter and used for humidifying the treated soil which leaves the purge bin.

Some hydrocarbon vapor will fail to condense. These will need to be destroyed thermally. The burner system that generates the heat for the Thermal Desorption process is an ideal place to vent the stream into. The schematic diagrams of the process flows for the above is shown in fig 13 and 14a & b show the integrated process flow diagram.

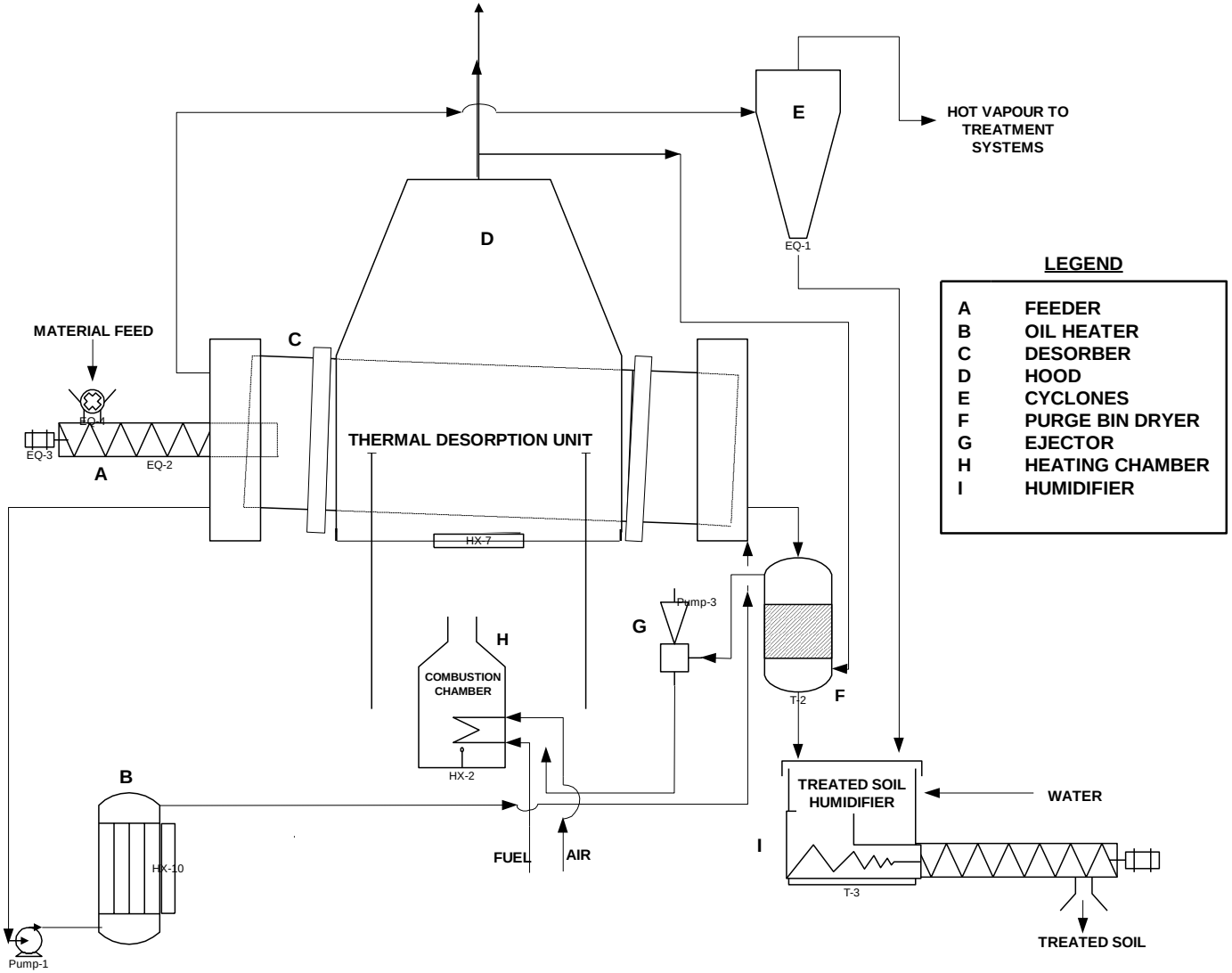


FIG. 13a: PROCESS FLOW OF THE SOLIDS PROCESSING SYSTEM

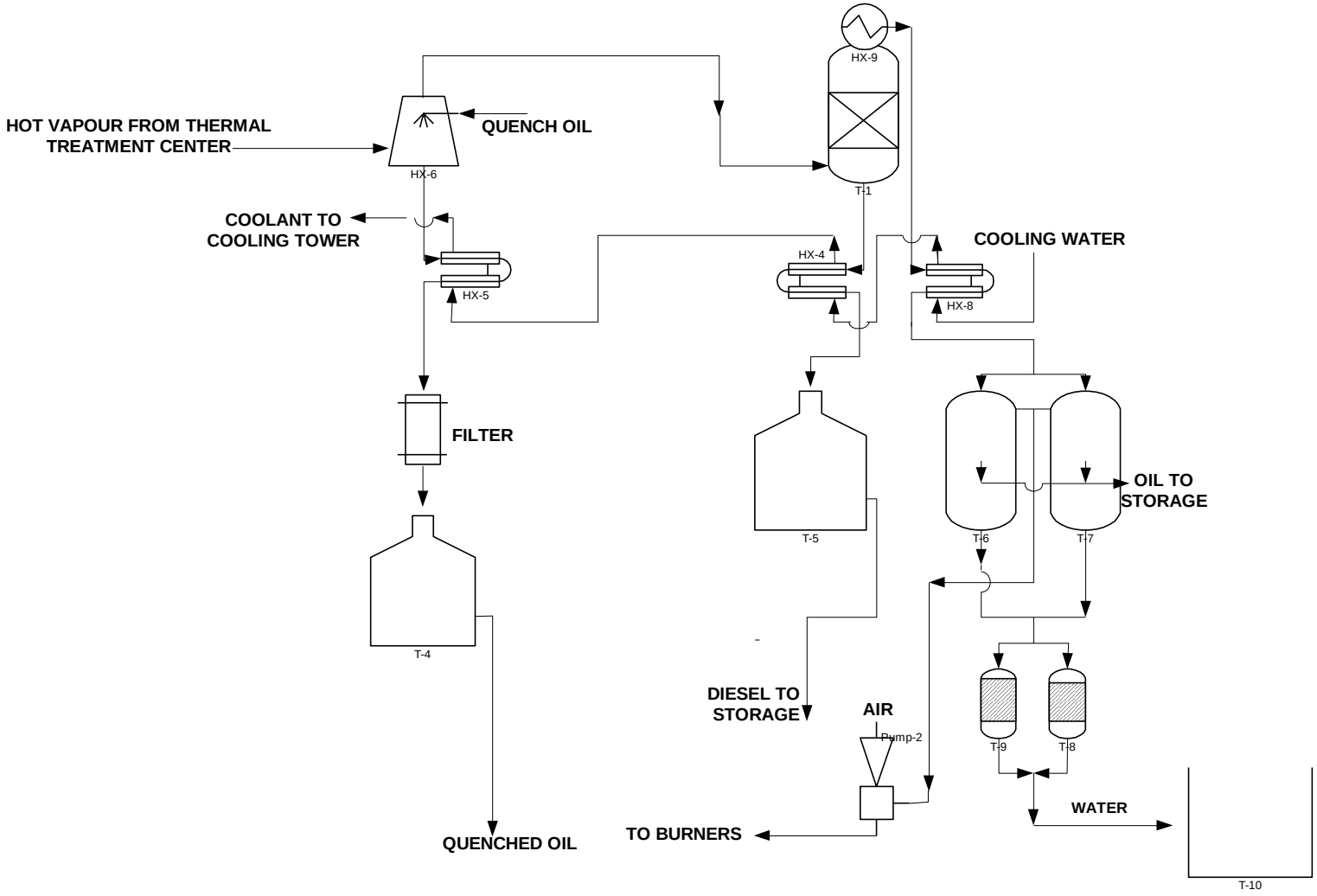


FIG 13b: PROCESS FLOW FOR LIQUID PROCESSING AND RECOVERY SYSTEM

5.3 DESCRIPTION OF DESIGNED PROCESS

5.3.1 FEED PREPARATION

The contaminated soils will be excavated using regular excavators and conveyed to a feed preparation area which is normally a shed for the purpose of inventory keeping and protection from inclement weather. Vibratory screens, crushers and shredders are used in effecting consistent feed with respect to size. A top size of 5cm is considered best for enhancement of heat transfer and transport inside the processor, (FREEMANN,H.M.). A belt conveyor transports the screened soil through a Rotary valve and screw feeder into the Desorber at a fixed rate. The Rotary valve effects the minimization of entry of air into the treatment system.

5.3.2 DESORPTION

Conceptually, the Desorber will be heated externally as the soil is fed into it at a steady rate, which will be determined experimentally. As the soil gets heated, it releases its volatiles (oil & water). The soil will spend some time in the system getting heated, agitated and transported. The volatiles that will be released will be withdrawn from the heating system by a slight vacuum pull created by an ejector or induced draft fan located down stream. At the end of the travel, through the desorber, the material will exit into a moving bed gravity dryer; (purge bin) here it will be intimately contacted for a very short time with recirculating hot flue gas as purge gas. This action strips the last traces of contaminant from the material due to higher temperature and more intimate contact. (PERRY; KIMBALL).

5.3.3 VAPOUR TREATMENT

The volatiles leaving the system (TDU) will consist of the following:

Hydrocarbons
Water
Particulate matter (Dust)

The dust will be removed by passing the stream through a set of cyclones placed in series. The “cleaned” vapor will then be processed by passing

through the Quench Chamber where oil is used to partially cool it to a temperature of about 350°C. Since dust is also knocked out here the stream will require filtration before it can be used for anything even heating of the Thermal Desorption System.

The vapor leaving the quench chamber will then enter a short fractionating column and dephlagmator assembly for knock out of the diesel fraction at temperature range of 200 - 350°C. This will be collected at the base of the column while the remaining vapor is passed through a total condenser. The liquid resulting from that condensation will be a mixture of water and hydrocarbons. This will be collected in a vessel, which will aid in disengaging the non-condensed gases.

The collection of this liquid (water & oil) is effected in two vessels (separators) positioned in parallel, with a swing arrangement and an ejector attached. The vacuum pull the ejector provides will effect the draft in the entire system. The outflow from the ejector will be channeled to the burner via a check valve for destruction of the non-condensed hydrocarbon Vapor.

The hot liquids exiting the Quench Chamber and the bottom of the fractionating column will be fed into two separate heat exchangers for cooling. They will thereafter be pumped to their storage tanks at ambient temperature.

The diesel produced will be used to power the Electricity Generator, which will power all the electrics in the project; as well as all the trucks and utility vehicles.

An electric motor driven air compressor provides all the air required for the project.

The water and oil mixture collected in the receiving tank will be allowed to separate and the water sent to a carbon bed filter for treatment and re-use in the wetting of the treated soil.

The hydrocarbon will be pumped back to facility or into the fuel tank for heating the process. When sludge is to be treated, the heating is done by hot oil (if the zone of operation is a hazardous zone). The oil will be heated in a remote and safe area and pumped to the process.

The treated soil exiting the purge bin will be mixed with water as it gets conveyed in a humidifier. This is to prevent dusting and enhance the movement of soil.

Integration of the process flow described above are shown in fig. 15 & 16 and figure 17 gives the materials flow based on treatment rate of 10,680 kg/h for soil and 5660k for sludge. Losses due to evaporation are disregarded in this material flow scheme.

The possible layout of the equipment to meaningfully achieve the desired process flow are shown in fig. 18 & 19. Since it is planned that these equipment will move from one contaminated site to another, the entire set of equipment will be laid out on three trailers.

Due to expected dust generation in the rotating chamber and expected imperfection in separation, some solid material will be carried over in dust stream while some volatile components will remain with the treated solid material.

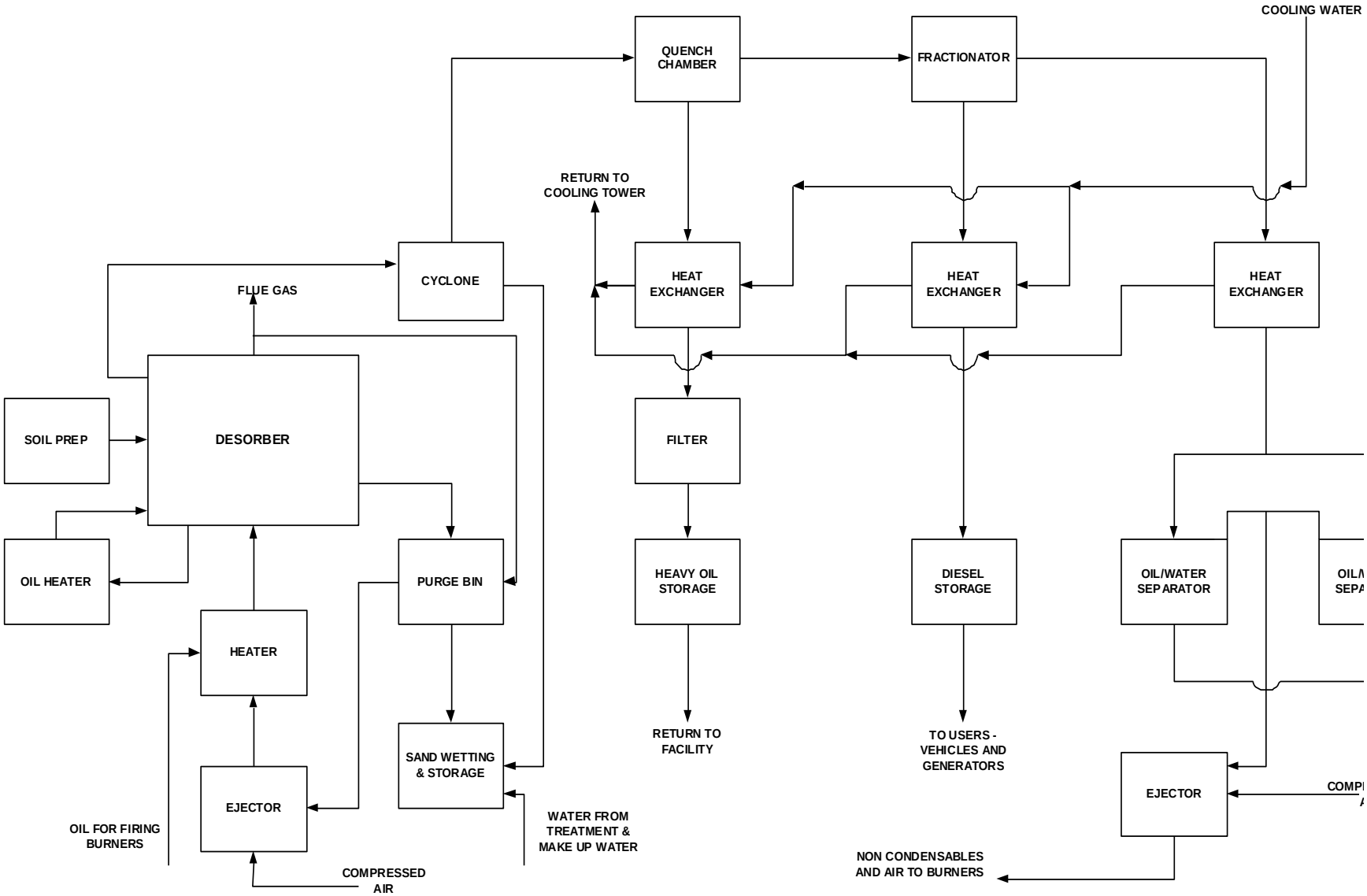


FIG. 12: BLOCK FLOW DIAGRAM OF THE TREATMENT PROCESS

FIG. 15: BLOCK FLOW DIAGRAM OF THE TREATMENT PROCESS

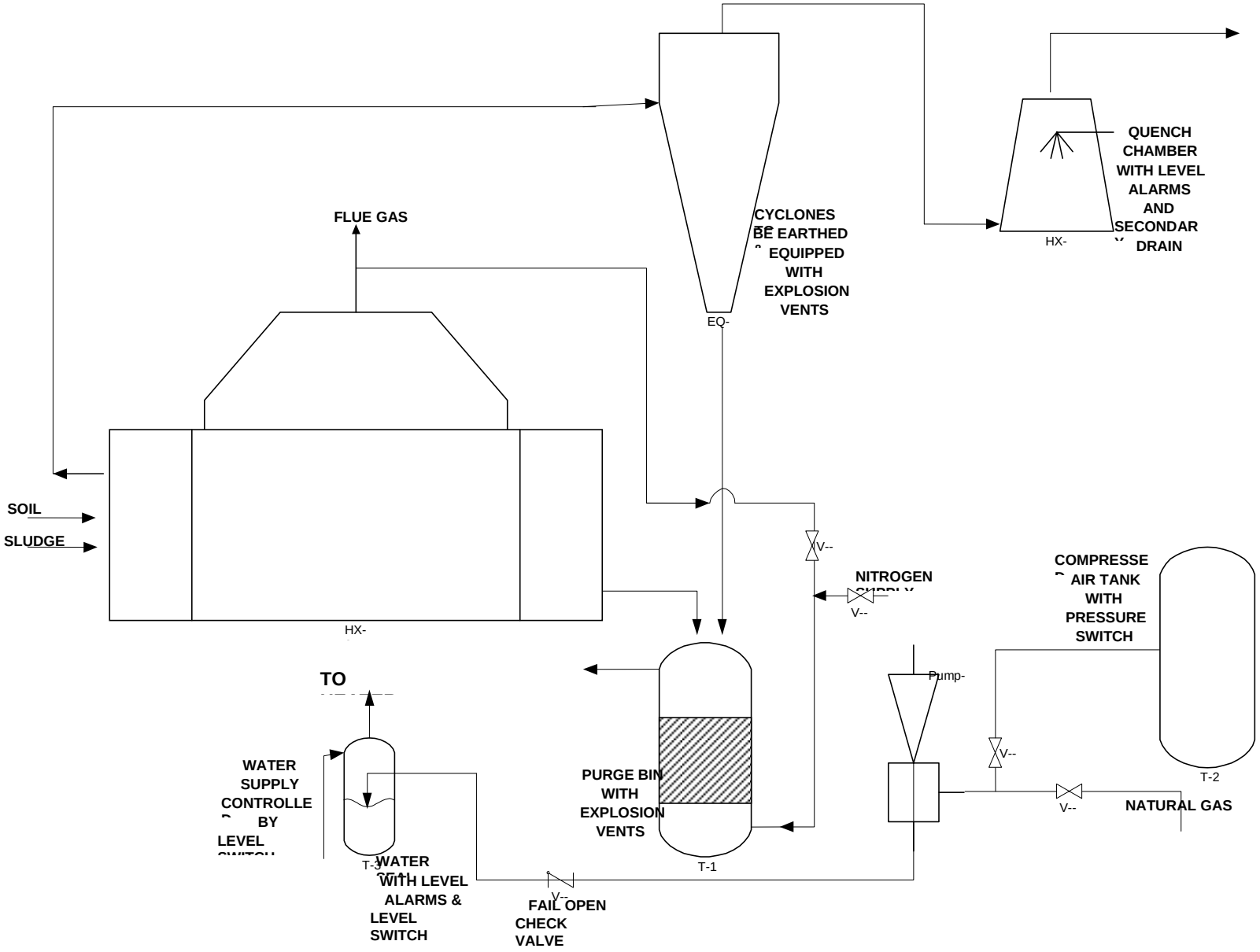


FIG. 16 MODIFICATIONS OF THE PROCESS FLOW DIAGRAM ARISING FROM SAFETY REVIEW

LEGEND FOR FIG. 16

A. Feed System (Conveyors & Rotary Valves)
B. Oil Heater
C. Desorber
D. Hood
E. Cyclones
F. Purge bin
G. Ejectors
H. Heating Chamber
I. Humidifier
J. Quench Unit
K. Heat Exchanger
L. Fractionator / Partial Condenser
M. Oil Receiving Tank
N. Diesel Receiving Tank
O. Light Oil & Water Receiving Tank/Separator
P. Activated Carbon Bed
Q. Treated Water Receiver
R. Fitter.

TABLE 7: STREAM CHARACTERISTICS (FROM PROCESS FLOW DIAGRAM FIG.16)

STREAM No.	NAME	COMPOSITION	TEMPERATURE	PHASE	REMARKS
i.	OILY SAND / SLUDGE	HYDROCARBON, WATER & SOIL/SILT	AMBIENT	SOLID/ LIQUID	STABLE & NOT FREE FLOWING
ii.	DESORBED VAPOUR	HC, WATER & DUST	UP TO 600°C	GAS	EASILY IGNITABLE
iii.	PARTIALLY TREATED SOIL	SOIL & HYDROCARBON	UP TO 650°C	SOLID	FREE FLOWING
iv.	TREATED SOIL	SOIL ONLY	UP TO 700°C	SOLID	FREE FLOWING
v.	FLUE GAS	INERT GASES	UP TO 900°C	GAS	IGNITION SOURCE
vi.	STRIPPED VAPOUR	FLUE GAS & HYDROCARBON	UP TO 700°C	GAS	NEDDS TO BE DESTROYED IN BURNER
vii.	EJECTOR OUTFLOW	AIR, FLUE GAS & HYDROCARBON	UP TO 400°C	GAS	STABLE
viii.	AIR	AIR @ 5-8barg.	AMBIENT	GAS	
ix.	DESORBED VAPOUR	HC, WATER & DUST	UP TO 550°C	GAS	DEDUSTED
x.	DUST	SOIL DUST	UP TO 500°C	SOLID	
xi.	DESORBED VAPOUR	HC & WATER	UP TO 300°C	GAS	FREE OF DUST
xii.	QUENCHING OIL	HC	AMBIENT	LIQUID	
xiii.	QUENCHED OIL	HC br >300°C	<240°C	LIQUID	PARTICLE LADEN

		SOLID PARTICLES			& HOT
xiv.	DESORBED VAPOUR	HC & WATER	< 250°C	GAS	FREE OF DUST
xv.	DIESEL	HC br 250 - 300	< 250°C	LIQUID	
xvi.	CONDENSATE	HC & WATER	< 40°C	LIQUID + GAS	
xvii.	NON-CONDENSABLE	HC	Ca. 35°C	GAS	NON-CONDENSABLE
viii.	WATER	WATER	AMBIENT	LIQUID	TRACES OF HC
xix.	OIL	LIGHT HC	AMBIENT	LIQUID	
xx.	WATER	WATER	AMBIENT	LIQUID	FREE OF HC
xxi.	WATER	WATER	AMBIENT	LIQUID	FOR HUMIDIFICATION
xxii.	EJECTOR OUTFLOW	HC & AIR	AMBIENT	GAS	
xiii.	QUENCHED OIL	HC & DUST PARTICLES	AMBIENT	LIQUID	PARTICLE LADEN
xiv.	QUENCHED OIL	HC	AMBIENT	LIQUID	DUST FREE
xxv.	DIESEL	HC	AMBIENT	LIQUID	DIESEL FRACTION
xvi.	HEATING OIL	HC / SYNTHETIC	> 400°C	LIQUID	
xvii.	HEATING OIL	HC / SYNTHETIC	< 250°C	LIQUID	
viii.	COOLING WATER	WATER	> 90°C	LIQUID	TO COOLING TOWER

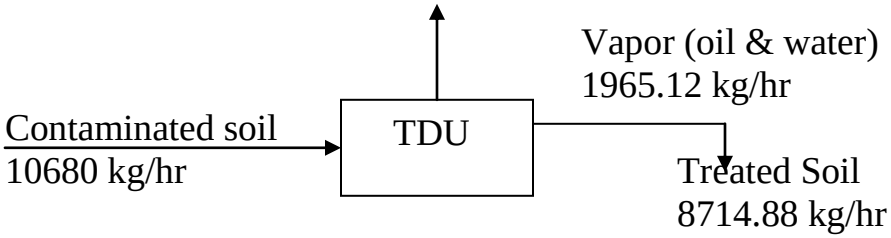
5.3.4 MATERIAL EVOLUTION

TABLE 8: MATERIALS COMPOSITION (Approximate)

	SLUDGE	OIL-CONTAMINATED SOILS
Average Oil content	45.8%	13.0%
Average Water content	47.5%	5.4%
Average Soil content	-	81.6%
Average Silt content	6.7%	-

On complete volatilizing of the oil and water, the materials balances for the system when treating either soil or sludge are shown below:-

a. Oil Contaminated Soils Treatment



b. Sludge Treatment

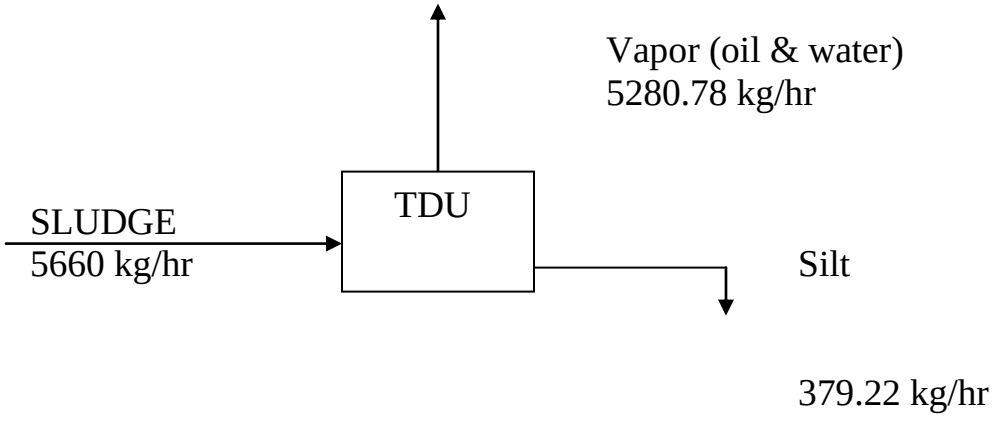


FIG. 17: APPROXIMATE MATERIAL FLOW

5.4 SAFETY REVIEW

Based on the fact that failure rate data for the system being developed is not available, a modified Hazard Identification procedure shown below was used for the process. [CROWL & LOUVAR].

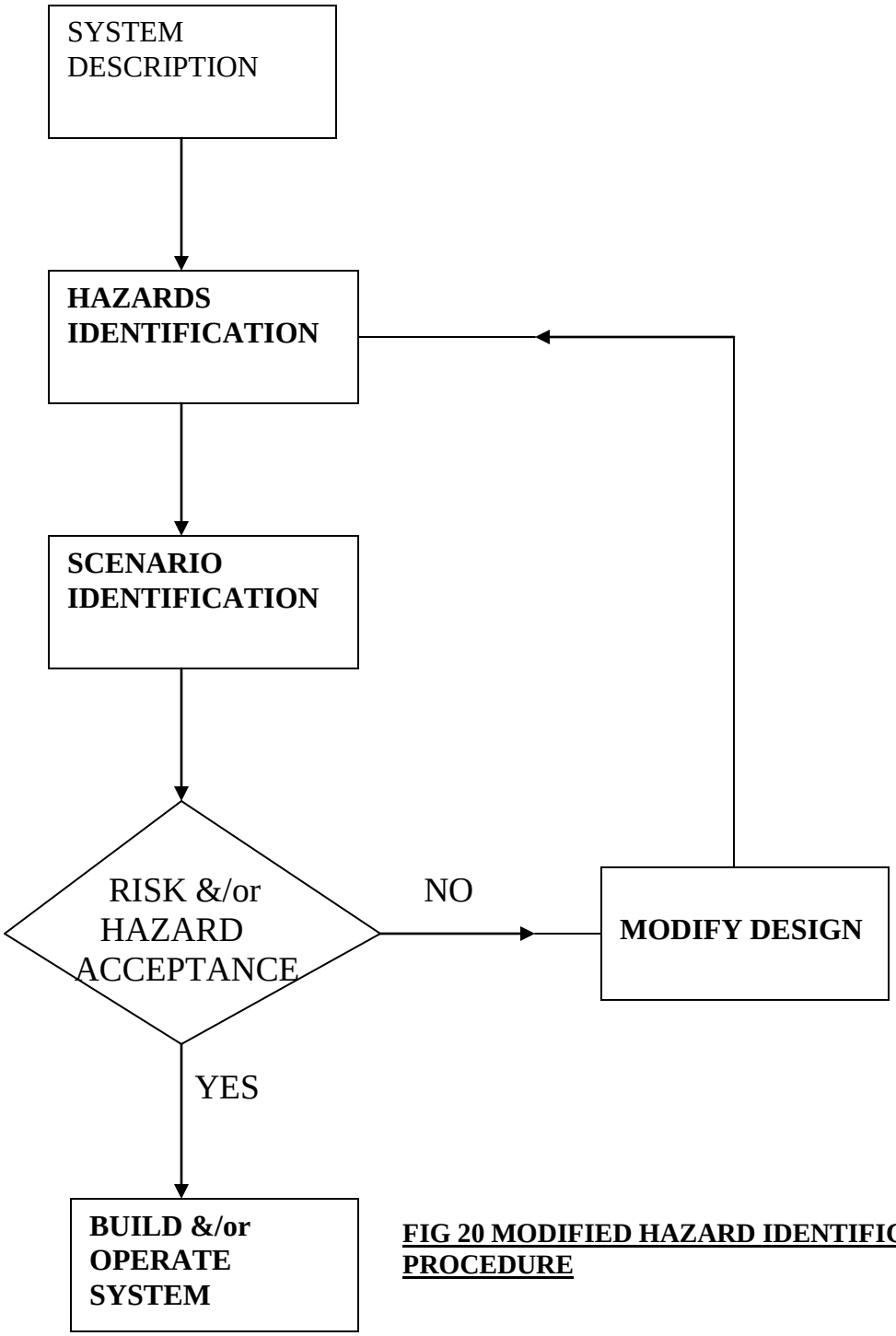


FIG 20 MODIFIED HAZARD IDENTIFICATION PROCEDURE

Common methods used for Hazards Identification include [CROWL & LOUVAR; STRANKS]:

Process hazard checklist
Hazards Survey
Hazards And Operability Studies (HAZOPS)
Safety review

Safety review being a very effective but less formal type of HAZOPS is chosen for use here. The formal type of Safety Review is used. It is known to provide good results and can be used almost immediately since it is relatively easy to apply. The team set up to conduct the Safety review was made up of an experienced safety personnel and an experienced Process Systems Engineer as well as a Secretary who documented the Safety review reports for the different sections of the process.

The review was carried out using the process flow diagram that was developed. (Fig.16).

SUMMARY OF THE SAFETY REVIEW

The following areas of the process were identified as requiring modification:

a) Safe delivery of Non condensable to the Thermal Oxidizer.

Solution:

i. A down stream positioning of a water seal, which the gases (with air) will pass through as they enter the burners.

ii. The use of a check valve, which can only fail open.

iii. The provision of a level gauge and audible low level alarm on the water seal.

iv. Provision of a pressure switch on the compressed air tank, which is filled by a dedicated compressor.

v. Preferential use of Natural gas whenever available as motive fluid for the ejectors.

vi. Level-actuated water fill-up of the seal.

b) Gravity Bed Dryer (Purge bin). Since this unit will have hot HC vapour and the flue gas may contain high amount of Oxygen, the system is prone to explosion.

Solution:

i. Inject Nitrogen into the flue gas being used as purge gas, to lower percentage of oxygen in the purge gas entering the dryer to levels below the lower Explosion limit (LEL).

ii. Provide explosion vents on the vessel.

iii. The explosion vents should be directed into a safe area.

c) Cyclone: Since the fluid entering has a high amount of HC and hot

dust, the presence (by leakage) of air may trigger an explosion due to electrostatic charges arising from dust handling.

Solution:

i. Earth (ground) the cyclone properly during operation .

ii. Ensure that all flanges are tight to minimize the possibility of leakage.

iii. Keep number of flanges at a minimum.

iv. Provide explosion vents.

d) Vapour transport through entire system

There exist the possibility of liquids rising in the Separators to levels that will interfere with the withdrawal/transport of the gases through the system.

Solution:

i. Provide a secondary drain chamber for each of the separators-Quench Chamber and Oil/water separators.

ii. Provide a high level alarm for the separators.

iii. Provide a passive overflow outlet on each separator.

e) Spill of received liquid: The liquid recovered will be pumped intermittently to storage. There could be spills from such procedure.

Solution:

i. The trailers will have sides covered to a height to enable the contaminent of such spills. Provide appropriate bund.

ii. The vessels that the pumps will evacuate will have low and high level switches to control the pumping sequence.

The modifications arising from this safety review are shown in fig.21.

Fig. 22: Show the final integrated process flow diagram.

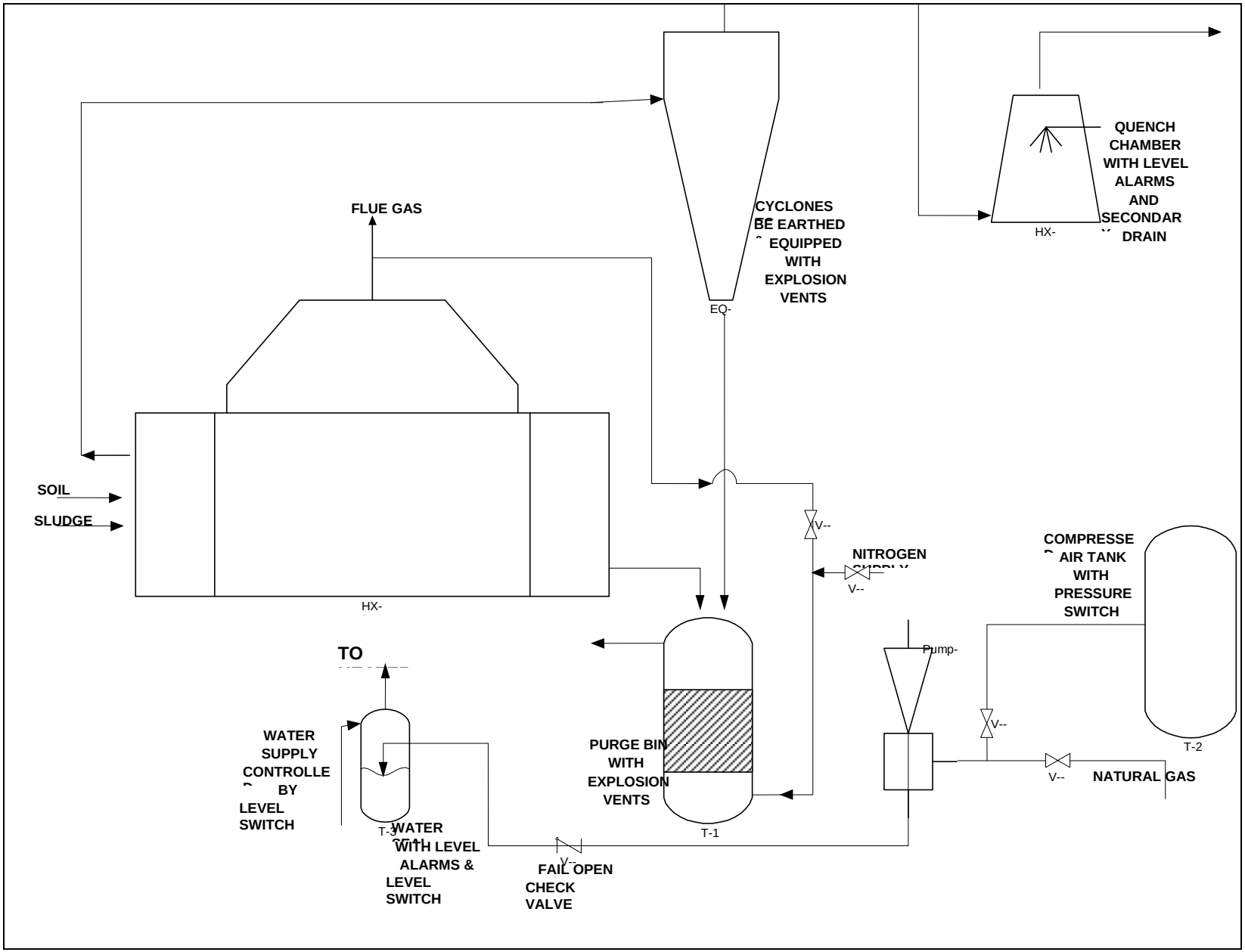


FIG. 21 MODIFICATIONS OF THE PROCESS FLOW DIAGRAM ARISING FROM SAFETY REVIEW

6.0 EQUIPMENT DESIGN FOR DEVELOPED PROCESS

BASIS OF DESIGN

Since the equipment assembly needs to be mobile as well as economically justifiable, a number of trailers will be used. The manner in which these equipment will be laid out on the trailers have been shown in figures 18 & 19.

The desorber should be able to fit onto a regular sized trailer of 2.5 x 12m. Therefore the maximum length and diameter of the Rotary desorber shall be 10m x 2m. This gives a length: diameter ratio of 5:1, which is within the acceptable range of such systems [PERRY, FREEMAN, NIESSEN].

6.1 EQUIPMENT SIZES AND SPECIFICATION

6.1.1 DESORBER

The following relationships are used: [PERRY; NIESSEN; SANTOLERI].

a. Time of Passage;

$$Ø = \frac{0.19L}{NDS}$$

Where: Ø is time of Passage in minutes
L is length of drum
N is Rotational speed (rpm)
S is slope of drum
D is diameter of drum.

b. Total Power Required;

$$bhp = \frac{N(4.75dw + 0.1925\ DW + 0.33W)}{100{,}000}$$

where:

bhp is Brake Horse Power
N is Rotational speed
W is Total rotating load (equipment & materials)
w is Live Load (materials)
D is Riding ring diameter
d is Shell diameter (external)

c) Holding rate:

$$\Phi = \frac{100\ F\emptyset}{V}$$

Where: Φ = Holding rate (%)
F = Throughput (m/min)
Ø = Residence Time (min)
V = Volume of Desorber.

6.1.1a SPECIFICATIONS

2.0 m Dia x 10m long

Rotational Speed:- Variable from 0.5 to 2rpm

Inclination (slope): 3 to the horizontal

Material of Construction: SS. 316 based on Temperature of Operation.

Material residence Time: 30 mins. (Variable; based on Rotational speed)

Feed Mechanism: Conveyor (Screw or Belt) through Choke Feeder for soils and 100 – 150 mm dia pipe through pump for sludge.

Drive requirement: 20 kw, geared 3 phase variable speed Electric Motor driving via Sprocket and chain.

Ride:	Riding belts (Steel tyres) positioned close to the two ends. (circumferentially).
Seal:	End boxes at two ends sealed against the Rotating shell by friction plates of brake lining consistency.
Heating:	External; Burners on the entire bottom of shell. *Internal; Stationary shell through which hot oil heated remotely is pumped.
Fuel:	Oils, Diesel, Natural Gas.

A schematic drawing of the Desorber is shown in figs. 22 & 23.

6.1.1b CAPACITY FOR PROCESSING

Hold up for Rotary drum is usually 10 – 20% of volume 15% being optimum. [PERRY; SANTOLERI; CORBITT, R. A]

$V = 31.42\ m^3$
Hold up = $3.142\ m^3$ - $6.284 m^3$

A residence time of 30 minutes is chosen based on the results obtained from bench top treatability studies. Therefore, the Desorber will process $6.284\ m^3$ of materials hourly. (minimum)

Residence Time	30 mins
Bulk density (soils)	1,700 kg/m^3
Bulk density (sludge)	900 kg/m^3
Processing Rate (soil)	10,680 kg/hour
Processing Rate (sludge)	5,660 kg/hour.

The Desorber is to be heated externally by gas and oil fired burners, as it rotates at a speed, which is variable from 0.5 to 2 rpm using a variable speed geared motor.

The oil contaminated soil will be fed into it using a screw or belt conveyor and a rotary valve for elimination of air. As the material enters the rotating drum, it gets heated by the hot metal, releasing the vapors of the oil and water it contains. A vacuum pull effected by an ejector located downstream

drafts the released vapor out of the desorber. The rotational motion and flights in the Desorber effect the necessary agigation for increased release of the volatiles.

The rotary motion and the slight inclination to the horizontal effect transport of the solid material through the chamber. At the end of the travel, it would have reached the optimum temperature, spending the desired residence time. The materials exit the chamber into a gravity bed dryer.

6.1.2 VAPOR TRANSPORT

MEANS:	Vacuum pull effected by three downstream ejectors which will use Compressed air when necessary or natural gas when available. They are positioned in parallel for effectiveness.
NATURE OF VAPOR:	Mixture of Hydrocarbons, Water, Dust and Leakage air.
VAPOR FLOW RATE:	0.5 to 1.2 m^3 /s
Size of Off-take Pipe:	150 to 200 mm diameter pipes of carbon steel.

6.1.3 FEED UNIT

Screw conveyor or belt conveyor through a rotary valve feeder.

A screw conveyor of following characteristics is adequate for conveying the soil up an incline of 30º at the required rate. [PERRY, CEMA]

i. Screw diameter 0.3m^3
ii. Capacity 45m^3 / hr at max. rpm
iii. Drive capacity 7.5 kw @ 75 rpm.

Belt speed: 30m / min
Horsepower (Drive): 1.5kw
Belt width: 0.35 m
Maximum lump size of materials: 80% below 50mm

Belt Material: Cotton of Special Rubber or Asbestos Fiber.

6.1.4 CHOKE FEEDER

Rotary Valve with Eight vanes of carbon steel construction, driven by 3.75 kw gear motor.

Diameter: 300 – 400 mm (Inlet/Outlet)

6.1.5 GRAVITY BED DRYER (PURGE BIN)

The bed of material being heated is constantly being agigated and mixed by the rotating motion and the internal flights in the Thermal Desorber. Because the material layer in contact with the heat transfer surface is constantly removed and mixed with the bulk material, product discharge is homogenous with respect to residual contaminant level and quality. [PERRY; LIEBERMAN & LIEBERMAN; SANTOLERI]

The material exiting the Desorber will then enter into the Purge bin through a rotary valve. In this Purge bin, the material will fall through counter current to purge gas taken as side spilt from the exhaust flue gas. A slight vacuum pull is effected on it using an ejector. It will therefore reduce the temperature at which the constant rate drying occurs as well as carry the evaporated volatiles, which leave the soil with hydrocarbon content less than 100 ppm.

The two stage drying will therefore ensure faster processing, larger throughput (capacity) and higher quality at no extra operational cost.

It has been established that purge bins effect efficient heat transfer between gasses and solids due to intimate counter current contacting [PERRY] and suppression of wet bulb temperature [KIMBALL]

Other advantages include:

a. Efficient heat and mass transfer.
b. Uniform distribution of gas throughout the solid bed effect the high efficiency of system.
c. Operational for low, medium and high temperature activities.
d. Flexibility of gas and solid flow rates and capacities.

e. Variable retention time of the solids.
f. Space economy with respect to throughput.
g. Ease of startup and shut down.
h. Ease of control by using the inlet and outlet gas temperature.

It is recommended that purge bins be made narrow and high to minimize the problem of non-uniform rate of solids movement downwards across the entire cross section. [KIMBALL]

The off gas leaving the purge bin will contain some hydrocarbon and will need to be destroyed. It is therefore piped into the burner for full oxidation.

See fig. 24 for schematic drawing of system.

6.1.6 CYCLONES

Cyclones are suitable for separating particles above 5 microns in diameter. Where agglomeration occurs, they can separate particles down to about 0.5 microns. Having no moving parts, they are relatively low cost methods of particulate removal.

The design parameters for high efficiency and high throughput cyclones are given in fig. 25, while fig. 26 & 27 give the performance curves for these two types of cyclones. [COULSON & RICARDSON]

Optimum Inlet velocity has been found to be 15 m/s. [COULSON & RICHARDSON; PERRY; ZENZ, F.A.]

Considering the need to withdraw the vapors generated in the Rotating Thermal Desorption System speedily, the high throughput cyclone will be more appropriate for this process. Additionally, downstream of the cyclone has a quench chamber operating which will knock out most of the remaining dust particles in the vapor stream.

Particulates enter the cyclone with the desorbed vapor tangentially, which forces the stream to turn. The larger particles having higher momentum cannot turn at the same speed with the lighter vapor and therefore impact on the cyclone wall and fall downwards into a collection hopper. The vapor stream turns a number of times in a helical path. The repeated turnings effect the break off of the particles from the vapor stream.

Factors affecting cyclone performance are [LEE & LIN]:

- Centrifugal force.
- Cut diameter.
- Pressure drop.
- Collection Efficiency.

Centrifugal force is given by

$F = \rho_p (d_p)^3 (V_p)^2\}/r$

Where ρ_p = Particle density (kg/m^3)

d_p = Particle diameter (μm)

V_p = Particle tangential velocity (m/s)

r = radius of circular path (m).

Therefore, the larger the particles, the greater the force acting in it. The higher the velocity the greater the force. On the other hand, the higher the radius, the lower the force. Hence smaller cyclones are more efficient. A set of cyclones positioned in parallel will be preferred for the above reasons. These will be arranged in series as well. Sets of parallel cyclones will be arranged in series to effect efficiency of particles collection with respect to size and throughput.

Cut Diameter: this is defined as the size (dia) of particles collected with 50% efficiency.

$$[d_p]_{cut} = \{9\mu B/[2\pi n_1 v_1(p_p - p_p)]\}^{0.5}$$

Where

$[d_p]_{cut}$ = cut diameter (μm)
μ = viscosity (kg/s-m)
B = Inlet width (m)
n_1 = effective number of turns (5 to 10 for common cyclones)
v_2 = inlet gas velocity (m/s)
ρ = particle density (kg/m³)
ρ = gas density (kg/m³)

This expression has been found to agree within 4mm for some experimental data.[LEE & LIN]

The higher the difference between the particle density and gas density ($\rho_p - \rho_g$) and the higher the number of turns, and the higher the inlet velocity, the lower the cut diameter; meaning that smaller-size particles will be collected.

Pressure drop in a cyclone due to entry and exit losses and friction and kinetic energy losses can be estimated using Stairmand's equation. (COULSON & RICHARDSON)

$$\Delta P = \left[\frac{\rho_f}{203} u^2_1 \left[1+2\left[\phi \frac{2rt}{r_e}\right] - 1\right] + 2u^2_2\right]$$

Where:
ρ_f = gas density (kg/m³)
U_1 = inlet duct velocity (m/s)

U_2 = exit duct velocity (m/s)
r_e = radius of exit pipe (m)
Φ = factor from chart Cyclone pressure drop factor
Ψ = parameter in the chart given by

$$\Psi = \frac{f_c A_s}{A_1}$$

f_c = friction factor taken as 0.005 for gases.

A_s = surface area of cyclone exposed to spinning fluid
A_1= area of inlet duct (m^2)

Pressure drop is high when gas is lean and decreases as the solids loading increase, up to about 3kg/m^3 and then starts increasing. [PERRY].

Similarly, collection efficiently increases with loading as shown in the figure 28 [PERRY].

The cyclone will therefore have the following basic operational parameters:

a. Inlet Velocity: 15m/s

b. Solids Loading in Vapor: <3kg/m^3

c. Mass Flow Rate (max): 1.5kg/s

d. Volumetric Flow Rate: 1.0 m^3/s

Minimum area of inlet duct = $\frac{1.0}{15} = 0.06m^2$

Dc = 0.48m
A cyclone of diameter 0.5 will be used.

Two units of this cyclone will be used in parallel while two additional units will be positioned in series. The tailings from them will be discharged into the humidifier through air locks.

It is desired that the streams (solid and vapor) remain hot vapor enough to prevent the possibility of any condensation of the desorbed oil vapor. The entire length of the piping carrying the desorbed vapor to the cyclone and the cyclones themselves will therefore be lagged.

6.1.7 QUENCHING UNIT

This equipment receives the de-dusted vapor from the cyclones. The purpose of the quench unit is two-fold:-

a. Complete the removal of the particulate matter (dust) from the desorbed vapor.

b. Cool down the stream to 350°C and condense and remove the heavier fractions in the process.

The liquid formed in this chamber need to be removed in-situ to reduce the possibility of entrainment in the uncondensed vapor leaving to downstream equipment. [PERRY; ULLRICH, R].

In order to eliminate the generation of additional vapor which will affect the effectiveness of the vapor transport device, the quench medium need to have the following properties:

a. Boiling above 350°C.

b. Complete miscibility with produced liquid (Hydrocarbon).

An appropriate medium will be lubricating oil or oil that had been previously recovered and filtered.

The quenching will be done by direct contact (i.e. the quenching fluid will be intimately contacted with the hot vapor).

The equipment is basically simple and cheap and is suitable for use with heavily fouling fluids such as the hot vapor, which may contain solid particles that escaped the de-dusting process of the cyclone. [SINNOTT]. Spray towers are easy to operate and with automatic temperature controls, only that amount of fluid is used that is needed to maintain the desired temperature of the exiting vapors [SANTOLERI]. The main design parameters are the diameter and height, which are approximately calculated as follows;

$D = \sqrt{\{4A/\pi\rho\}}$ and $Z = 2.0D$ where A, the area of the tower is given by $A = Wb/\rho$ and b is a dimensionless constant in the range 0.1-0.3 and W is mass flow rate the vapor of density ρ entering the quencher.

The vapor will enter the column and rise counter current in a short column against the cold quench liquid, which will be pumped and sprayed at the top.

A liquid seal is effected at the base of the column to prevent any migration of the vapor into the produced heavy oil delivery system. The only vapor that may leave through that route will be as a result of dissolution of the lower boiling hydrocarbons in the quench liquid. The temperature of the vapor leaving the Quench Chamber will be maintained at 350° ± 10°C using the flow rate of the quench liquid. Based on the temperatures that this system will experience the most effective quenching liquid is oil. It is therefore economically wise to use previously cooled (recovered) oil. This is compatible with the materials in the stream and will not generate vapors that will give rise to extra load downstream.

It is necessary to sub cool this liquid prior to transfer to storage. Since the amount of sub cooling required is large, (ca 250°), it is more efficient to effect it in a separate exchanger [SINNOTT].

The liquid produced from the quenching operation (which is a sum of the Quench liquid used and the fraction condensed out of the vapor stream plus dust) will be transferred to storage via a filter bed, which will remove all the entrained particles. A gravel bed filter shall be used and will operate passively with another unit being in redundancy. This will make it possible to clean the filters without stopping the process irrespective of the frequency of fouling.

This is shown schematically in figure 29.

A heat exchanger will therefore be positioned between the Quench unit and the filters. This shall be a simple double pipe type exchanger. Fig. 30. It is cheap and can be made as effective as one wants by connecting several units in series. The advantages of this type of heat exchanger include low cost, easy cleaning when fouled, easy to fabricate and use, and ease of increasing capacity. [SEIDER et al, SINNOTT]

6.1.8 DIESEL MAKING UNIT

The vapor leaving the Quench Chamber will be drafted into the unit, which will separate out the diesel fraction. This is essentially a partial condenser since it is only required to cool the vapor stream from 300°C to 200°C ± 10°C. Again, the coolant that can be economically used is oil (the heavy fraction used in Quenching).

The partial condenser shall be a small diameter packed column. The variation of the flow rate of the coolant will provide the essential control on the exit temperature of the vapor. The coolant used here will be used in the quenching operation upstream.

6.2 PRODUCT SPECIFICATIONS AND OPERATING CONDITIONS

The aim is to produce diesel (Automotive Gas Oil) from the desorbed vapor. This is a complex mixture of numerous hydrocarbons, which is specified on the basis of boiling range, as 180° – 300°C. The diesel produced and used in Nigeria was distilled and has the boiling range of 200 – 320°C.

The operating conditions shall be as follows:

- CONTINUOUS FEED & PRODUCT WITHDRAWAL
- ATMOSPHERIC PRESSURE (IT WIL ACTUALLY OPERATE AT A VERY SMALL NEGATIVE PRESSURE).
- THE COLUMN WILL PRODUCE ONLY TWO STREAMS – TOP AND BOTTOM PRODUCTS.

6.2.1 CONTACTING DEVICE AND COLUMN INTERNALS

The feed shall be vapor at maximum temperature of 300°C. The desire is to condense and remove all materials boiling above 200°C. Therefore the contacting device need not be special. A simple metal grid will be used as support for the packings.

6.2.2 REFLUX REQUIREMENT

Since the separation required here is very simple, reflux requirement can readily be met by a partial condenser positioned on top of the column. This is shown schematically in fig. 32.

The operating conditions of this partial condenser will effect the desired provision of reflux. The temperature of the top product (i.e. vapor) will be the controlling factor for the partial condenser. It should be 200°C minimum.

Again the super cooling required for the produced diesel is large but can be effectively provided by a set of double-pipe heat exchangers.

Alternatively, the vapour may be processed simply by partial cooling to condense fraction boiling above 200°C while allowing the vapour (<200°C) to travel on to a total condenser. This is shown in fig 32.

Bench top tests on the materials gave the following average compositions of the vapours desorbed for Oil Contaminated Soils and for sludges as shown in table.

The tests were carried out as follows:

2 kg of each of the material was heated in a steel pot to 650°C for 1 hour.

All the vapor was condensed using chilled water.

The volume collected was re-distilled using laboratory distillation set up and the fractions collected and measured.

All the soils came from one location and all the sludge came from one tank. The average contents of each fraction for soil and for the sludge are given below:

Material	<310	200 - 310°	<200 including water	Non – condensables (Balance)
Oil Soils	43%	11.3%	39.4%	6.3
Sludge	38%	15.7%	41.2%	6.1

The test did not take into consideration the vapors that could not condense in the initial desorption experiment.
It is therefore possible to assume that at least 11% of the recoverable liquid from a typical 13% oil-contaminated soil will be of diesel consistency.

6.2.3 LIGHT OIL AND WATER CONDENSATION

The vapor leaving the Diesel making unit will be condensed totally in a heat exchanger. The condensate (mixture of light hydrocarbon and water) will be collected on separators, disengaged from the non-condensable gases and treated as follows:

a. OIL STREAM: Returned to facility or used in firing the burners.

b. WATER: Pumped through a carbon bed filter to adsorb trace hydrocarbons and sent for use in the Rehumidifier.

c. NON-CONDENSABLES: This is sent to the burners for total destruction.

6.2.4 VAPOR TRANSPORT

A vacuum pull at the end of process flow effects the transport of the desorbed vapor through the entire process. This vacuum shall be passively provided by an air ejector which shall use Natural gas when available or Compressed air otherwise.

Air ejectors are known to be able to passively handle high vapor flow rates. [SINNOTT, PERRY]. A number of units will be positioned in parallel.

6.2.5 UTILITIES REQUIRED

a. POWER: The TDU, pumps, air Compressor and electric lights shall be powered by a Diesel engine driven generator. A 250 KVA generator will be adequate. Total power requirement is 150 KW if all equipment are operating.

b. AIR: An electric compressor which will deliver about $10m^3$ of air per minute at 8 bar will be installed for the provision of primary combustion air, air for ejector and air for general cleaning. The compressor will feed a central air tank at 8 bar from which the user stations get serviced.

c. WATER: This will be brought in for the following:

a. Oil Cooling
b. Process Cooling
c. Soil humidification
d. General cleaning
e. Safety

All the equipment and tanks for these utilities shall be mounted on a separate Trailer.

EQUIPMENT	DIMENSIONS	MATERIAL	TEMPERATURE RANGE	REMARKS
THERMAL DESORPTION	2.0m dia. x 10m	Stainless Steel 316	External: 950°C Internal: 650°C	20 – 30min Holdup
CYCLONES	500mm diameter (main body)	Stainless Steel 316	Internal: ≤ 650°C	High throughput design
PURGE BIN	1.0m dia. x 2.0m	Stainless Steel 316	Internal: ≥ 700°C	
VAPOR TRANSPORT	150-200mm dia. pipe	Carbon Steel	≤ 600°C	
HUMIDIFIER		Carbon Steel	100 - 600°C	
HEAT EXCHANGER	50mm dia.Tubes in a shell	Stainless Steel	From Ambient To 600°C	
GAS-LIQUID SEPARATOR	1mm dia x 2mm	Carbon Steel	Ambient	
EJECTOR (Inlet: Outlet)	150:200 dia.	Carbon Steel	Ambient	
BURNER	1,500mm x 2,500mm	Stainless Steel	> 1000°C	
FRACTIONATING COLUMN	250mm dia x 1000mm	Carbon Steel	200 - 300°C	

TABLE 9: LIST OF MAJOR EQUIPMENT IN THE PROCESS.

7.0 DESIGN OF PILOT UNIT

7.1 GENERAL

Several parameters of the Thermal treatment system selected for the oil contaminated soils and sludges in the Niger Delta are unknown and need to be explored/evaluated, [FELTMAN, W. R @ 173-01] in a pilot system. In the process design, certain operating conditions were assumed. The pilot plant, when used to treat the materials will confirm the design and operating conditions for the full-scale system. The pilot plant will also be used in establishing economic parameters such as processing costs, maintenance costs etc. These have been shown to be the main drivers in profitable winning treatment projects rather than technical edge and performance of solution to a problem [ACHARYN, P. AND BIOLECHINI, R @ IT3-01]. It will also provide the very important proof-of-concept demonstration.

Thermal treatment systems are typically the most costly treatment system. However, a large part of this cost is due to the energy costs and capital costs. [FRTR,-Remediation Technologies Screening Matrix and Reference Guide Version 4.0 EPA 2005]. The pilot plant will be used to establish the possibility of creating an energy independent system, which will therefore operate with zero cost with respect to energy.

With respect to the secondary re-use of the treated soil; thermal systems tend to create situations in which the natural organics in the soil are destroyed. However, when operated a low temperatures the thermal systems can operate well enough to retain the natural soil organics, which permit the re-use of the soil for agricultural purposes. [FRTR, Remediation Technologies Screening Matrix and Reference Guide Version 4.0 EPA 2005]. The pilot plant will evaluate the possibility of operating at such temperatures with effective treatment of the soil, meeting the set targets. This is important because of the agricultural base of the indigenes in Niger Delta.

The parameters that will be evaluated using this pilot plant are:-

a. Oil recoverability
b. Residual oil in treated soil
c. Optimum retention time
d. Fuel requirement per unit of material
e. Throughput analysis
f. Diesel recovery for power generation
g. Retention time – Temperature relationships

7.2 COMPONENTS OF THE PLANT

The components (equipment) which comprise the pilot (prototype) are as follows:

1. Feed screw conveyor
2. Choke feeder (Rotary Valve)
3. Externally heated Rotary Drum
4. Drive System for the Rotary Drum
5. Gravity Bed Dryer
6. Vapour Condensing System
7. Dust Collection System
8. Air Ejectors
9. Burners for heating Rotary Drum
10. Piping for cooling water
11. Temperature monitoring panel
12. Skid on which the main equipment are mounted.

The pilot plant is shown figures 34 & 35

The characteristics of two of the above listed components, which are considered of major importance in the process system are detailed below:

7.2.1 ROTARY DRUM

1 Length 3m (2.8) – heated
2 Diameter 0.7m
3 L: D of 1:4
4 Hold up at 15% of Volume = $0.15 \times (0.35)^2 \pi \times 3 = 0.173m^3$
5 Residence Time; Variable, 15 mins – 30 mis
6 Heating; Gas flames (external)
7 Material: Stainless Steel 316
8 Rotational speed: Variable between 0.5 – 2 rpm
9 Inclination; Fixed at 2° to the horizontal.
10 Feeding: Continuous Via choke feeder (Rotary Valve)
11 Product withdrawal: Gravity into secondary processor.

7.2.2 GRAVITY BED DRYER

1. Diameter: - 0.4m, effective hold-up $\simeq (0.2)^2 \pi \times 1.5$
2. Height: - 1.5m (effective height)
3. Material: - Stainless Steel
4. Heating medium: - flue gas from Rotary Dryer
5. Monitors:- Temperature at 2 points (midway and bottom)
6. Orientation:- Vertical
7. Material Transport:- Gravity counter current with hot flue gas.
8. Internal:- Baffles and weirs

8.0 PILOT PLANT OPERATIONS

8.1 DIRECTIONS FOR THE PILOT TESTS

The objective of the test is to effect the following:

Establish the theoretical treatment capacity of the pilot in terms of Hold up based on size and with contaminated soil of 20% oil content.

Establish the oil recoverable with the unit working fully and treating to completion.

Establish oil retained in soil at various temperature of bed and at fixed retention time.

Establish oil retained in soil at various retention times and at fixed operating temperature.

Establish optimum Residence (Retention) Time, Temperature and Treatment rate.

Establish volume of oil recoverable at the doubling of through-put.

Establish residual oil at various through-puts while maintaining optimum retention time.

Establish the best temperature for the soils exiting the Rotary chamber into the Gravity bed dryer.

8.2 PROCEDURE FOR THE EXPERIMENTS

The following steps were adopted for the experiments using the Pilot Desorber:

8.2.1
A Material Preparation

i. Soil which had not been affected by oil was excavated and freed of all vegetations.

ii. Batches of this soil were mixed with crude oil to make a 20% oil content soil.

iii. In order to achieve effective and uniform material, the mixing was done using a motorized concrete mixer.

iv. For uniformity of quality of the soil, all the soil-oil mixings were carried out on the same day and the mixture stored in a covered bay using plastic sheets.

v. Samples were taken from this mixed batch for tests on oil content and moisture content.

B Test

1. The Pilot desorber is firstly put into rotary motion at 1 r.p.m..
2. Burners are then ignited. (LPG is the fuel).
3. The ejectors are initiated using water jet.
4. The coolant flow through the heat exchanger is initiated.
5. When the chamber attains the desired operating temperature, the soil is speedily fed into the rotating chamber using RAM feeder.
6. At the end of feeding, the system is closed to the outside leaving only the vapour outlet.

7. Heating of the rotating desorber continues for the desired duration of the test and is stopped while rotation continues.

8. Soil sample is taken out from the sample port and kept for analysis.

9. At th end, the chamber is evacuated and prepared for the repeat test or another test.

10. Repeat tests or new tests are started only after the chamber has cooled to ambient and has been cleaned.

8.3 RESULTS OF THE TESTS

8.3.1 OIL RECOVERABLE

Pilot desorber was loaded with 200L (0.2m³) of the contaminated soil and treated without withdrawing any solid product for 1 hour. Bed temperature was 650ºC for 35 minutes. Samples were taken from the bed and analysed for remnant oil at 5 minutes intervals. The volatiles were totally condensed and kept in a conical vessel. The water was carefully separated from the oil and both measured at the end. This initial test was done three times, on the same day.

Results are presented in table 10.

TABLE 10: Residual Oil Content At Different Retention times.

Time	Bed Temp.	Oil Content:1	2	3	Average
0		13.0	13.3	14	13.4
5	650ºC	12.6	12	12.3	12.3
10	650	10.8	9	10.4	10.7
15	650	6.9	6.3	6,7	6.6
20	650	4.1	3.9	4.0	4.0
25	650	1.5	1.8	1.2	1.5
30	650	0.3	0.6	0.3	0.4
35	650	0.1	0.1	0.1	0.1
40	650	0.1	0.1	0.1	0.1

- Time 0 is the state of the material on attaining the desired Bed Temperature.
- The Bed Temperature ranged from 642-655ºC.
- Temperature was limited to 650ºC based on the range for High Temperature Thermal Desorption [CIRIA VOL II & VOL III; NIESSEN]
- The water jet is used for vapour drafting so as to minimize loss of hydrocarbon vapour as the water and hydrocarbon mixture would be condensed and cooled totally before separation.

- Water recovered was not measured as it was already mixed with the motive water for the ejector.

Time	Oil Content
0	13.4
5	12.3
10	10.7
15	6.6
20	4
25	1.5
30	0.4
35	0.1
40	0.1

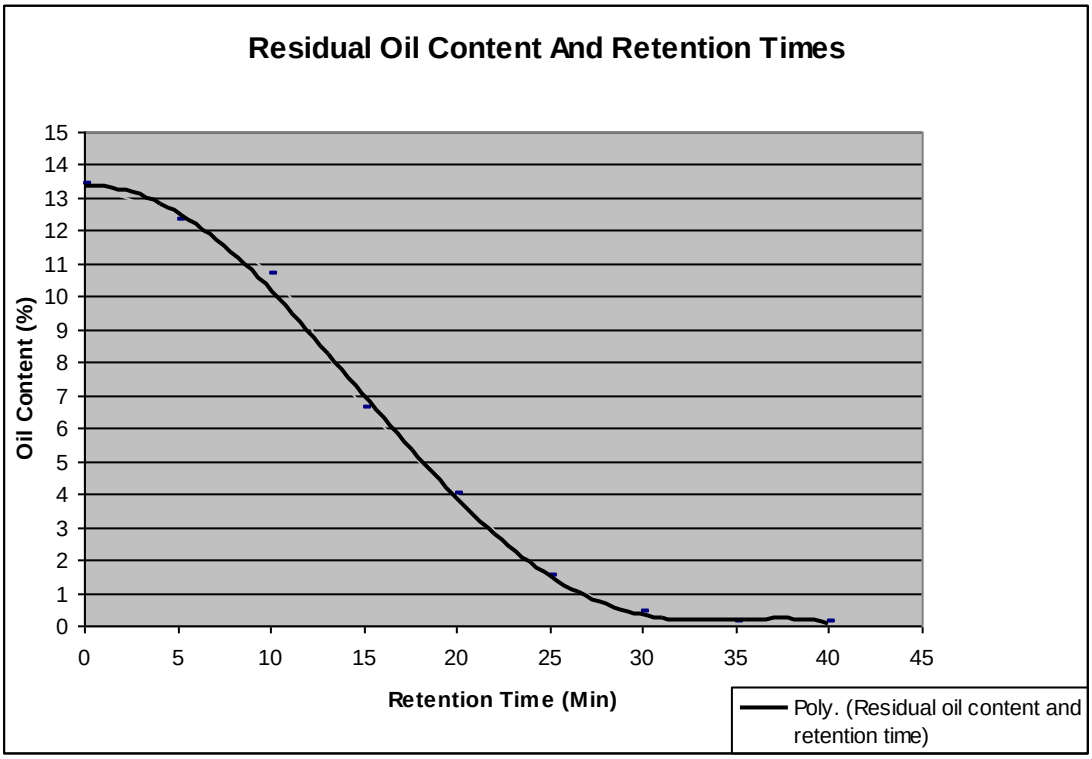


Fig. 36

8.3.2 OIL RETAINED IN SOIL AT VARIOUS BED TEMPERATURE AND FIXED RETENTION TIME

Three maximum bed temperatures (300, 450 and 650ºC) were used to evaluate the extent of desorption at 60 minutes of residence of the soil in the chamber.

Each test was conducted three times with each experiment starting from ambient. The oil left in the soil at the end of retention was measured.

TABLE 11: Oil Retained in soil after treatment at varying temperature and fixed retention time 60 minutes.

S/N	300	450	650
1	6.5	0.5	N.D
2	7.3	0.3	N.D
3	6.3	0.55	N.D
AVERAGE	6.7	0.47	-

- ND = Non Detectable

8.3.3 OIL RETAINED IN SOIL AT FIXED TEMPERATURE AND VARYING RETENTION TIMES.

Based on the results obtained in the 60 minutes retention time test, it was necessary to evaluate the system at the medium temperature of 450ºC while varying the residence times 15 minutes 20, 25 and 35 minutes were chosen; the aim being to ascertain practically, the temperature time combination that gives the best results while meeting targets. The temperature of 450ºC lies between the ranges for Low and High Temperature desorption [CIRIA VOL VII].

Oil contents of the soil at the end of retention were measured. Again these tests were done three times.

In each case, the soil was brought up to the temperature of 450°C and held there for the desired retention, time, by turning down or off the external gas heaters.

The holding temperature swung from 420 – 470°C

TABLE 12: Oil retained in soil after treatment at fixed Temperature (450□C) and varying residence times.

	1	**2**	**3**	**Average**
10	N/A	N/A	N/A	N/A
15	6	5.3	5.5	5.60
20	4.6	4.4	4.4	4.47
25	3.8	3.9	3.8	3.83
30	2.8	3.0	3.2	3.0
35	2.0	2.1	2.2	2.1

8.3.4 RECOVERY OF OIL AND RESIDUAL OIL AT INCREASED THROUGHPUT

The pilot system was brought to a temperature of 650°C and the matrial (oil contaminated soil) charged at different quantities (to simulate increase in throughput) while the heating continued. The system was allowed to run for the desired retention times of 30 minutes and 45 minutes and shut down. The vapour generated was condensed and the oil recovered measured. The hot soil was sampled and allowed to cool for tests for residual oil content. Volumes treated were 0.2m³, 0.24m³, 0.3m³, 0.4m³ and 0.44m³. This limit was placed by the physical dimension of the pilot-desorbing chamber shown in figure below. The temperatures of the bed at the end of each retention time were also measured and recorded. The densities of the oils were measured and recorded.

The results are shown in table 13 and 14 below and graphically in figs 36 & 37.

Vol. Thr. Put	T.	1.25 T	1.5 T	1.75 T	2.0	2.25T
Oil Recovered (%)	81	80	78.1	73	70	65
Residual Oil Cont. (%)	0.48	1.2	3.6	7	10	12.5
Final Temp. °C	600	570	500	380	370	350
Rel. Density of Oil	0.91	0.90	0.87	0.82	0.81	0.80

Table 13: Volume of oil recovered and Residual oil content at various increments of throughput and fixed retention time (30 minutes). T=0.2m³.

Vol. Thr. Put	T.	1.25 T	1.5 T	1.75 T	2.0	2.25T
Oil Recovered (%)	80.6	81	80.8	80.8	80.9	80.3
Residual Oil Cont. (%)	<0.1	<0.1	0.3	1.0	2.0	3.1
Final Bed Temp. °C	650	650	620	580	510	480
Rel. Density of oil	0.92	0.91	0.91	0.90	0.91	0.88

Table 14: Oil Recovered and Residual Oil Content at various increments of throughput and fixed retention time of 45 minutes.

OIL RECOVERED (%)	THROUGHPUTS	RESIDUAL OIL CONT. (%)
82	1	5
80	1.25	7.5
78	1.5	17.5
75	1.75	35
70	2	50
65	2.25	75

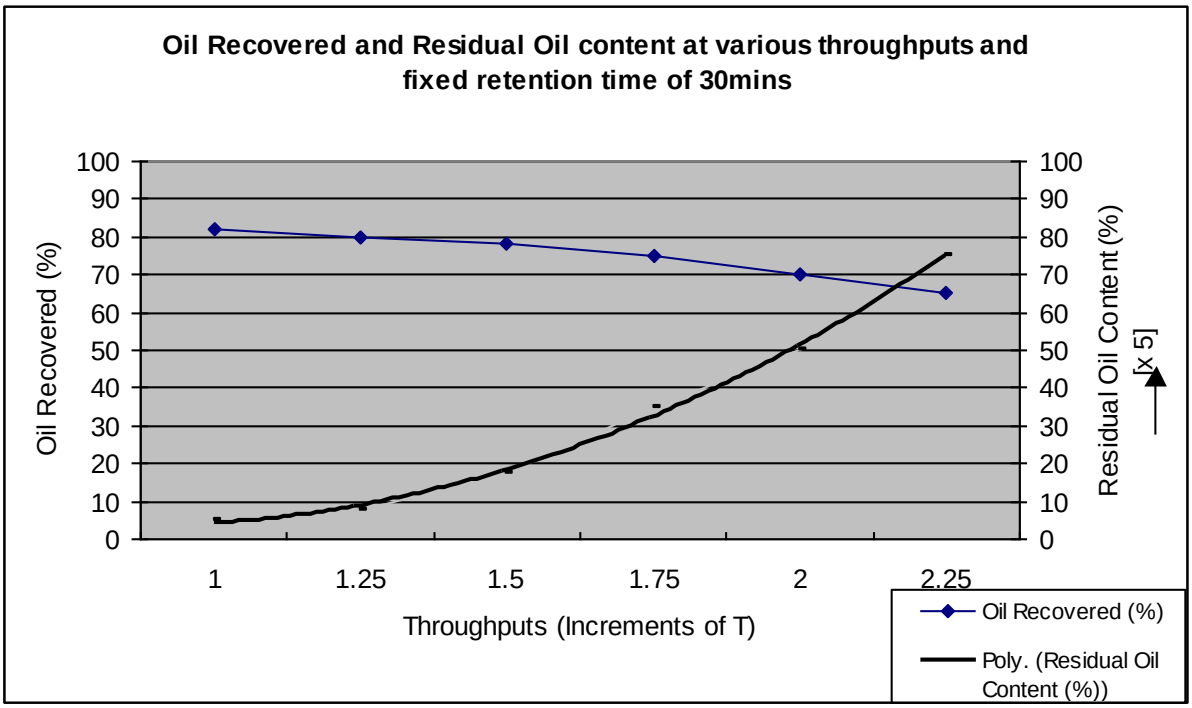


Fig. 37

OIL RECOVERED (%)	THROUGHPUTS	RESIDUAL OIL CONT. (%)
80	1	0
80	1.25	0.5
80	1.5	1.5
80	1.75	10
80	2	15
80	2.25	20

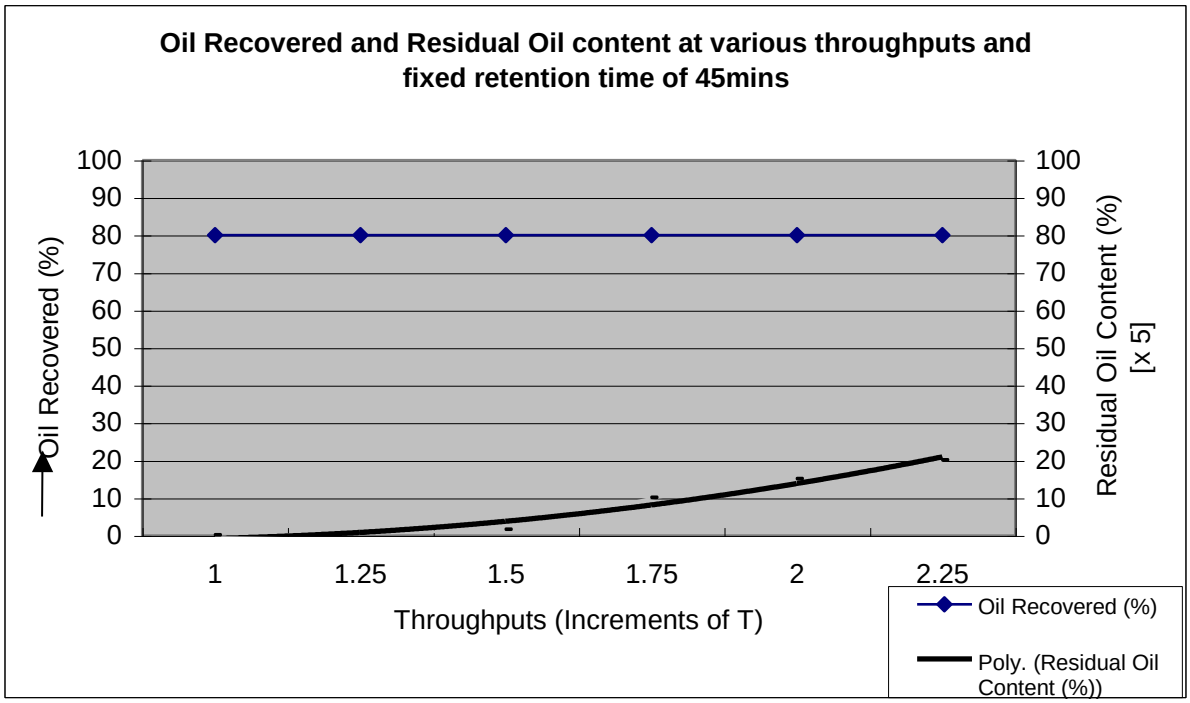


Fig. 38

8.3.5 EFFECT OF THE GRAVITY BED DRYER

Retention times of 45 mins and 30 mins were used at throughput of 2.0T to evaluate the effect of the gravity bed dryer.

Hot flue gas at 950°C – 1000°C was passed counter current to the descending partially treated soils. After a residence time of approximately 10 mins, the soil exited and was tested for residual oil content. Table below shows the results.

	Initial Oil Content of Soil	**Final Oil. Cont. after G.B.Dryer**
30 mins	20%	0.5%
40 mins	20%	Non Detectable

8.4 PROCESS CONTROL REQUIREMENTS

For the developed process to be operated at a steady state, and be resilient inspite of external disturbances, control systems need to be configured for a number of critical portions of the process system. [SEIDER; TURTON, R].

In order to effect adequate plant wide controls, the entire process was divided into the following subsystems:-

Materials Treatment

Vapour Recovery & Heat Exchangers

Product Storage & Accessories

The controls basically necessary for each of these subsystems are discussed below.

8.4.1 CONTROLS NECESSARY FOR THE MATERIALS TREATMENT SUBSYSTEM

Oil Contaminated Soils or Sludge will be prepared and fed to the Thermal Desorption System via a screw or belt conveyor. Feed rate will be dependent on the temperature in the heart of the TDU. A by-pass will be initiated if the temperature falls below a certain level and feed re-initiated when the temperature recovers.

The heating of the Thermal Desorption Unit will be controlled using a solenoid valve controlled by a Temperature Controller, which directly senses the temperature of the product. The fuel supply to the burners is the manipulated variable.

The purge bin receives the product of the TDU and uses part of the flue gas to effect the purging. This is drafted by an ejector, which subsequently moves the purge gas and entrainments into the burner for destruction. The control required for this system is largely on product quality, which directly depends on the temperature. A temperature controller will directly affect the rate of flow of the purge gas through the purge bin.

The treated solid will need to be optimally humidified prior to collection for

re-use. The ideal temperature for the humidification ranges from 95°C-105°C. [CORBITT,R; US-EPA].

Temperature can be used to effectively control this operation. A Temperature Controller will therefore control the water flow into the humidifier.

The dedusting action of the process is rather passive and will not require any controls. The desorbed vapor should freely go into the Cyclones and the dust-free vapor should leave as freely as possible. The solids dropped at the base of the cyclone should however be removed through a rotary valve which should ensure positive seal in the system since the vapors are traveling under the effect of the reduced pressure created by the ejector located downstream .

These controls are indicated on the process flow diagram shown in fig. 39

8.4.2 CONTROLS FOR THE HEAT EXCHANGER NETWORK

The dedsorbed vapor will be quenched to 300°C in the Quench Tank. The quenching fluid will be previously cooled oil. The temperature of the exiting vapor will control the flow of the quenching oil into the tank.

The vapor leaving the quench tank will be cooled partially to produce diesel using oil as coolant. Again, a temperature controller will control the flow of the coolant using the temperature of the exiting vapor as input.

The cooled liquids collected separately as Heavy oil, diesel and light Hydrocarbon-Water mixture will need to flow out freely steadily or periodically into the receiving tanks.

The controls are shown in fig. 40.

LEGEND FOR HEAT EXCHANGER NETWORK

STREAMS	IDENTIFICATION
A1	WATER (L) – COLD
A2	WATER (L) – HOT
A3	WATER (L) – HOT
A4	WATER (L) – HOT
B	DESORBED VAPOUR
C	HEAVY OIL
C1	HEAVYOIL – COLD
D	DESORBED VAPOUR
E	DIESEL
E1	DIESEL – COLD
F	DESROBED WATER
G	WATER + HC + NON CONDENSABLE
H	WATER + HC (L)
I	NON CONDENSABLE
J1	HEAVY OIL – COLD
J2	HEAVY OIL- HOT
K	HEAVY OIL – COLD
L	HEAVY OIL – (J2 + K)

TABLE 15: Stream identification for the Heat Exchanger Network

V1 = Quench Chamber with separator for cooled liquid.

V2 = Cooler for final cooling of Quench liquid. (Sub cooling)

V3 = Partial Condenser for Diesel production.

V4 = Cooler for final cooling of diesel. (Sub cooling)

V5 = Total Condenser for all remaining vapor.

V6 = Separator for non condensables.

8.4.3 LIQUID PRODUCTS STORAGE SUBSYSTEM

The main controls necessary here are to effect the swing from one receiving tank to another on filling up. This will require the shutting down of three valves and the corresponding opening of three other valves in a cascading but non uniform manner. The actions need to be controlled by the level controller which need to be in the receiving tanks. Due to the complexity of this system, and based on the need to have the process simple and robust, it is better to install an audible level alarm and have an operator effect the swings. Additionally, the receiving tanks should have sufficient capacity to allow for relatively long periods between swings – eg one hour.

All the liquid storage tanks will be fitted with level alarms and level switches shall be connected to the pumps which evacuate the tanks. These will effect low level shut off of the pumps.

9.0 ANALYSIS OF RESULTS OF PILOT TESTS

9.1 DISCUSSIONS OF PILOT TEST RESULTS

9.1.1 RESIDUAL OIL CONTENT

The results presented in table 9 and fig 36 show the variation of oil left in the material with the time retained in the desorption chamber without varying the temperature.

Bulk loss of the volatiles was experienced down to 25minutes of retention time. Thereafter the energy input did not evolve as much volatiles. This is probably due to the nature of the volatiles. The heavy ends of the crude oil (which boil at higher temperatures) will evaporate last. Conclusively, the system does not have to keep processing the material after 25 mins if energy savings are to be considered. This may be a possible consideration for transfer to secondary drying unit.

9.1.2 RESIDUAL OIL AT DIFF. TEMP & FIXED RETENTION TIME

The results shown in table 10 indicate that 300ºC is too low a temperature to effect substantial desorption of the volatiles, while 650ºC is too high for the retention time of 60 mins used. The material was effectively treated at 450ºC using the same residence time.

However, it is possible to prefer an operating temperature of 300 in conjuction with a secondary dryer if energy savings are the principal considerations. Throughput is the more desirable parameter.

9.1.3 RESIDUAL OIL AT DIFFERENT RETENTION TIMES & FIXED TEMPERATURE

From the table 11, the material is not treated to completion when held at that temperature for up to 35 minutes. However, it is clear that the soil after 30 mins of residence has not lost enough oil to be fed into the secondary drying chamber.

9.1.4 RESIDUAL OIL & OIL RECOVERED AT INCREASED THROUGHPUT

One of the objectives of project is to recover the oil contained in the material and convert part of it into Diesel. The main constraint therefore is to ensure that enough volatiles are recoverable for the sustainance of the energy need. At both levels of retention time (30 mins & 45 mins) the least percentage oil recovered was 65%. A soil that has 15% oil content which is being processed at 10 tonnes/hour will have 1.5 tonnes of oil available hourly, of which 0.975 tonnes or 1,150L is recoverable. Based on the bench top tests carried out as detailed in 6.2.2, there is the possibility of obtaining 120 litres of diesel hourly from the volatiles. This is more than adequate to power a 250 KVA diesel engine generator, which consumes about 21 litres of diesel per hour as well run the vehicles.

The balance of the oil (1020L) will be available for firing the burners. Another objectives of the project is to have a system that will process significantly more than it's design capacity to the treatment levels imposed by the Department of Petroleum Resources of Nigeria Ministry of Petroleum & Natural Resources.

The secondary drying unit will be able to function well (ie counter current and gravity effect) if the soil is free flowing. For this to be, the residual oil content of the soil need to be low enough. Values ranging from 2 to 4.0 are satisfactory. These values were obtained at the following combinations of throughput and retention times; 1.5T and 30 mins; 2.0 T and 45 mins and 2.25T and 45 mins.

The optimum values are 1.5T and 30 mins, which will be equivalent to 3 times the normal throughput hourly. For subsequent economic evaluation purposes double throughput is used. (ie 2T)

9.2 ENERGY CONSIDERATIONS

9.2.1 FUEL FOR HEATING

Treating 1 tonne of oil contaminated soil containing 20% moisture will require 100m³ or 66.4kg of Natural Gas in an indirectly heated Thermal Desorber [CIRIA VOL VII; USEPA; Yaws, C]. This value has taken the losses into consideration.

To treat 10 tonnes hourly, the quantity of gas required will be 1000m³ or 664kg. This will cost $500 (US) or £350 (British) N66,400 (Nigerian) in Nigeria.

Therefore a process that provides its own heating fuel will have an operational savings of £8,400 daily or £2,520,000 in a 300-day operational year.

9.2.2 FUEL FOR GENEREATORS & VEHICLES

Secondly, based on the capacity of the system to process double the normal throughput with the same energy expense, it is clear that the savings in energy is actually double. ie £5,040,000 annually.

Thirdly, the other fuel and energy needs of the process shall be met by the use of the diesel that the process will produce.

Basically, the electricity generators will use about 160,000 litres per annum while the vehicles could use 45,000 litres. This total represents a cost of £54,000.

In a year of processing – ie in 300 operational days, the process system will make energy savings that are far above the capital costs

10 SOCIO-ECONOMIC EVALUATIONS

10.1 CAPITAL COST ESTIMATION

The cost of building the pilot unit which has a processing capacity of 1 Tonne/hour is used to estimate the approximate cost of the full 10 tonne per hour system using the relationship.

$$Cp_1 = Cp \left[\frac{A1}{A2}\right]^{0.6} \quad \text{(Seider, W.D et al)}$$

Where:

CP2 is the cost of the pilot system = £3,600

A1 is the area of the main plant

A2 is the area of the pilot

$$Cp1 = 3{,}600 \times \left[\frac{84.7}{1.36}\right]^{0.6}$$

$$= £42{,}944$$

This is the estimated cost of the main item of equipment in the entire process developed. The relative weight of this equipment cost to the others in the system combined is known to be of the order of 3:1.

Using this the approximate capital cost of the developed system is not expected to exceed £128,000 (Pounds Sterling) or $193,250 (USD) or ₦32,000,000 (Nigeria Naira).

Capital cost has been taken as the major basis in evaluating the costs of the developed process and existing systems.

Other costs that affect the total project cost are as follows:

10.1.1 INDIRECT COST

These include freight costs, custom duties and taxes as well as insurances. In the imported systems duties are charged by the Nigerian Government at 5 – 7% of the equipment cost.

Freight costs are also substantial. A conservative total of extra 10% can be used to cover these indirect costs.

Such costs are totally absent for systems developed, fabricated and tested in Nigeria.

10.1.2 INSTALLATION COSTS

The systems designed and built outside Nigeria will necessarily require foreigners to effect the installation. The costs are therefore expected to be higher in such cases than for locally made units.

Installed costs (Bare Module Capital Cost), which include the cost of materials and labour as well as capital costs is given by the summation of the various costs [GUTHRIE].

Capital Cost = Cp

Materials for Installation Cm = 0.17Cp

Direct Labour CL = 0.37 (Cp + Cm) = 0.63 Cp

Freight Insurance & Taxes CFIT = 0.08 (Cp + Cm)

Construction Overhead Co = 0.70 CL

Contractor Engineering Expenses CE = 0.15 (Cp + Cm)

Bare Module Capital Cost = 3.18 Cp

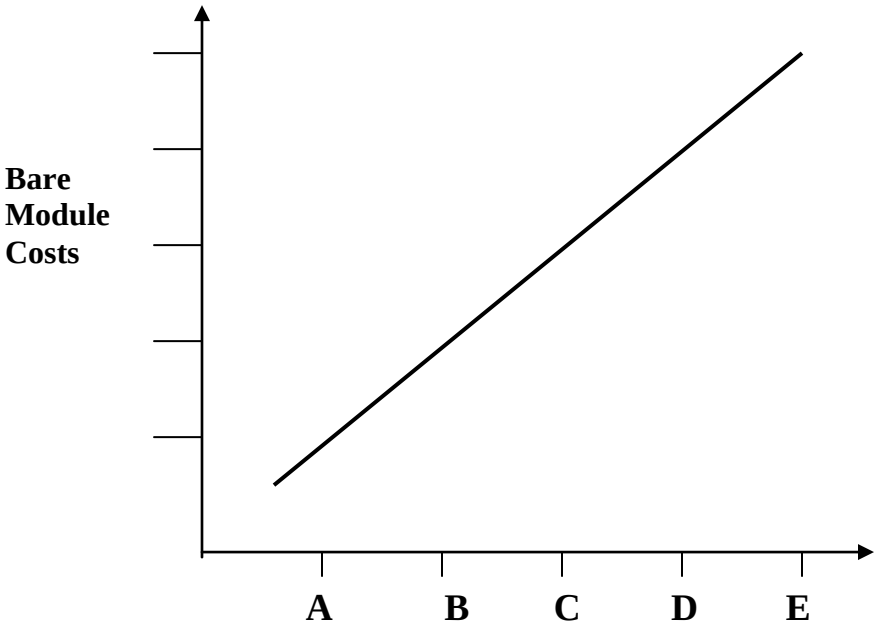
These are shown in table 14 below for cases of capital costs ranging from £128,000 for the developed system to £500,000.

Table 16: Bare Module Cost Estimation for different basic capital costs

COST PARAMETER	A_1 (A_2) *	B	C	D	E
Capital Cost Cp	128,000	200,000	300,000	400,000	500,000
Materials Cost Cm = 0.71 Cp	90,000	142,000	213,000	284,000	355,000
Cp + Cm	218,000	342,000	513,000	684,000	855,000
Direct Labour Cost C_L = 0.37 (Cp + Cm)	80,000	126,540	189,810	253,080	316,350
Freight Insurance Taxes C_{FIT} = 0.08 (Cp + Cm)		27,360	41,040	54,720	68,400
Construction Overhead Co = 0.7 C_L	56,462	88,660	132,867	177,156	221,445
Contractor Engineering Expenses CE 0.15 (Cp + Cm)	32,700	51,300	76,950	102,600	128,250
Bare Module Cost (BMC)	387,822 (405,262)*	635,778	953,667	1,272,556	1,589,445
Percentage Increase		64%	140%	228%	310%

*A2 represents a system purchased externally at some price with developed system.

The variation in costs is shown graphically in figure 41 below:



From published quotations received by various clients from original equipment manufactures and vendors for process systems, which can treat soils in Nigeria, the prices range from £400,000 to £850,00 (Capital Cost only) [DPR NIGERIA]

None of these systems offers the possibility of recovering oil contained in the soil matrix. All of them will use energy provided by firing fuels purchased for the operation. All of them will be operated and maintained by international personnel (expatriates) which are essentially much more costly. The comparative operational costs are discussed below.

None of the system will have availability in terms of operating hours like the developed system. None of then is mobile. Mobile units cost more. It was not possible to ascertain how much more.

10.2 OPERATIONAL COSTS ESTIMATION

TABLE 17: ANNUAL OPERATING COST FOR THE DEVELOPED SYSTEM & AN IMPORTED SYSTEM

ANNUAL	BASIS	DEVELOPED SYSTEM	IMPORTED SYSTEM
FIXED			
Maintenance	10% (BMC)	38,782	127,156
Operating Labour	24	288,000	288,000
Laboratory	4	96,000	96,000
Supervision*	4	72,000	192,000
Plant Overheads*	8	72,000	192,000
Local Taxes	2%	7,750	25,400
Insurance	2%	7,750	25,400
License Fees	1%	3,875	12,700
VARIABLE			
Fuel	21600m^3	--	50,000
Electricity		--	3,000
Water		--	--
Air		--	--
Miscellaneous		10,000	10,000
TOTAL		**£597,000**	**£1,022,000**
ROUNDED		**£597,000**	**£1,022,000**

NOTE: The costs that are personnel related are affected by the expatriates salary rates.

Hence operational cost is expected to be about half for the system being developed compared with the imported system.

10.2 OPERATING COST ESTIMATION

The fixed operating costs that apply to this process are as follows;

- Maintenance
- Operating Labour
- Laboratory costs
- Supervision
- Plant Overheads
- Local Taxes & Rates
- Insurance
- License fees & Royalties

While the variable operating costs are

- Utilities (including fuel)
- Miscellaneous operating material

The table below shows an approximate comparison between the total project costs for the developed system and an imported system each capable of processing 10 tonnes of soil per hour.

10.3 ECONOMIC ANALYSIS

	Developed System	Imported System
Bare Module Cost	387,822	1.271,556
Operating Cost (2yrs)	1,194,000	2,044,000
TOTAL	**£1,581,822**	**£3,315,556**

TABLE 18: TOTAL PROJECTS COST FOR 2 YEARS OPERATION

The comparison is based on similar processing capacity. It has also been assumed that the two equipment will have the same availability. This is not necessarily true. However, it is obvious that the imported system will need to process at least twice as much materials as the developed system to break even.

At the processing rate for oil contaminated soils of £70/tonne, their breakeven quantities will be about 23,000 tonnes for the developed system and 47,000 tonnes for the imported systems, which are approximately 100 days and 200 days operations for the respective systems.

It is therefore possible to substantially reduce the treatment costs for the developed system and still achieve the breakeven point before the imported system.

10.4 SOCIOLOGICAL BENEFITS

The system developed will be built in Nigeria. The detailed engineering for the entire process plants will be done locally in Nigeria using International Standards. The fabrications will be done entirely in Nigeria and by Nigerians. One of the few things that must be done from Europe or USA is the procurement of the materials of construction and machineries such as motors, pumps as well as control instruments and steel.

The major advantage that will arise from this is the ability for Nigerians to readily maintain the plant and naturally improve on it as time goes. This is the reason why it can be given a life span as short as 5 years.

Another advantage is the economic empowerment that Nigerians will have from building and operating such a system. Foreign exchange is conserved, more people are employed. The expertise to tackle such process developments will be gradually built up.

11 CONCLUSIONS & RECOMMENDATIONS

The process system developed has the following unique features:

a. It is able to treat oil contaminated soils and sludges at twice the treatment rate that is usual for similar size mobile processes.

b. It is able to treat the contaminated soil without any dependence on third party for energy. It receives oil from the soil, produces diesel from the oil and uses part of the diesel and oil recovered for powering the generators and heating the process. Typically, $100m^3$ of Natural gas is required to treat 1 tonne of soil for heating purposes only [CIRIA VOL. VIII].

c. It is able to return some oil to the owner of the facility or sell such oil for secondary earnings.

d. It shall be available at prices lower than 50% of the capital cost involved in the purchase of foreign made systems.

e. Operational & Maintenance costs are much lower for this system.

f. It shall be able to offer the service of treating oil contaminated soils and sludges to clients at rates that are as low as $70/tonne (£50/tonne) without compromising profitability or return on investment.

A pilot plant used for the project has been built & tested for the purpose of evaluating the basic design and assumption of advantages. It is recommended that a more site relevant pilot system be designed and built which will process materials continuously at the rate of 1 tonne/hour. This unit will be used to evaluate the on-site reliability and flexibility of the system. Actual revenue generation capacity will be evaluated using this as prelude to the design, fabrication and commercialization of the main plant which will treat no less than 20 tonnes per hour of oil contaminated soils.

12 FUTURE WORK

Process optimization studies need to be carried out on the developed system.

The effect of moisture and oil content on processing costs and time will need to be investigated.

It will also be beneficial for fuller understanding and improvement to develop a simulation model for the whole process.

It is recommended that a unit which will process 1 tonne per hour continuously and which will be site-relevant be built and deployed to the fields for the purpose of establishing the operational parameters which will; aid in optimization studies and activities.

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